Development of a Knowledge Assessment System Based on Concept Maps and Differential Weighting Approaches

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ABSTRACT

This study explored the feasibility and practicability of designing and developing a Knowledge Assessment System (KAS) for assessing different types of knowledge as defined in the revision of Bloom's Taxonomy (Anderson et al., 2001). The KAS created as a result of this study is based on concept maps and employs two differential weighting approaches. It is a developmental study, which includes the design phase, development phase and evaluation phase. The general software system design model (Sommerville, 2009) was adopted to guide the design of the Knowledge Assessment System based on its procedures, including system requirements analysis, architecture design, component design, interface design, and database design. The assessment criteria in this system are designed to be proposition-based and consist of either a non-weighting approach or a weighting approach, which can help provide instructors with flexible assessing methods as well as help them obtain a whole picture of what kinds of knowledge their students have grasped and to what extent the students have mastered that knowledge, based on the student-created concept maps. The two differential weighting approaches initially compare student-created concept maps with expert maps stored in the system. Because some correct propositions in student concept maps may be not included in the initial expert concept maps, the system is designed to continually refine the assessment criterion by inspecting and evaluating the correctness of the propositions in the student-created concept maps and adding the results to the system's database.

The current system is able to assess three types of knowledge: factual, conceptual, and procedural, all of which are defined in the revision of Bloom's Taxonomy (Anderson et al., 2001). The assessment process begins with the assignment of different types of concept map tasks entered and stored in the Knowledge Assessment System. Following by student completion of the tasks and submission of a concept map, the submitted concept map is compared to the criteria stored in the system and a performance report is generated.

The research results show that the Knowledge Assessment System based on concept maps and two differential weighting approaches can act as a useful tool for assessing students' factual, conceptual and procedural knowledge based on their concept maps.

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Chapter 1: Introduction and Need for the Study

Concept maps have been used broadly to promote as well as to measure student learning during the past decades (Edwards & Fraser, 1983; Hagemans, van der Meij, & de Jong, 2013; Liu, 2010; Monroe-Ossi, et al., 2012; Novak, 2010; Novak & Cañas, 2008; Rye & Rubba, 2002; Stuart, 1985; Shavelson, Lang, & Lewin, 1994; Soika & Reiska, 2014; Wang & Dwyer, 2004).

Developed in a research program at Cornell University in 1972, concept maps were used by Novak and his colleagues to inspect the changes of science knowledge in children (Novak & Gowin, 1984; Novak, Gowin, & Johansen, 1983). According to Novak and other scholars' perspectives, a concept map is a graphic tool consisting of nodes, linking phrases and directional linking lines. A node represents a concept; two nodes connect with linking phrases through a directional linking line to form a proposition and produce a meaningful statement (Novak, 1990; Ruiz-Primo & Shavelson, 1996).

Usually, concept maps are represented in a structure such as hierarchy concept maps, net concept maps, and flow chart concept maps. These different structural concept maps are very similar to knowledge representation in human brains. Hence, concept mapping is recognized as a means for students to display their understanding of curriculum content. Additionally, concept maps are used to organize and represent knowledge and help students clearly express their knowledge visually, as well as help teachers evaluate students' conceptual understanding of domain knowledge (Alonso-Tapia, 2002; Anohina-Naumeca, 2015; Clariana, Engelmann, & Yu, 2013; Gouli, Gogoulou, & Grigoriadou, 2003; Herl et al., 1999; Laffey & Singer, 1997; Novak & Cañas, 2008; Petrovic, Jeren , & Pale, 2013; Ruiz-Primo, 2004; Ruiz-Primo & Shavelson, 1996; Williams, 1998).

In fact, using concept maps to evaluate students' understanding of a subject-domain knowledge has been broadly examined. The research results by different scholars have indicated that concept maps could act as a viable assessment tool for evaluating the knowledge structures of students, and making a diagnosis of the students' misconceptions as well as missing concepts "when scored appropriately" (Chung et al., 2006; Fisher, 2000; Herl et al., 1999; Lee, Jang, & Kang, 2015; McClure, Sonak, & Suen, 1999; Novak & Cañas, 2008; Ritchhart, Turner, & Hadar, 2009; Rye & Rubba 2002; Strautmane, 2014; Yin et al., 2005; Yin & Shavelson, 2008). Here, it might raise the question: why does it need to score appropriately?

Different types of knowledge like conceptual knowledge and declarative knowledge exist according to various scholars' perspectives, and these scholars have investigated the utility of concept mapping tools for assessing different types of knowledge. For example, Williams (1998) conducted a study for assessing students' conceptual knowledge based on concept maps. Shavelson, Ruiz-Primo and Wiley (2005) explored assessing students' declarative knowledge based on concept maps. It seems that the roughly defined knowledge attributes and qualities could not give a clear picture for the knowledge assessment with concept mapping activities (Petrovic et al., 2013). Another question is raised: what kind of knowledge can be assessed with concept mapping?

Paper-based concept maps are inconvenient for students to revise and maintain, and they are difficult for instructors in terms of providing real-time feedback; evaluating student-created concept maps by hand is especially subjective, inefficient and inconsistent (Chang, Sung, & Chen, 2001; Liu, 2010; Nesbit & Adesope, 2006). Several computer-based assessment tools based on concept maps have been developed by various scholars (Anohina-Naumeca et al., 2011; Cañas et al, 2004; Chung et al., 2006; Fisher, 1992; Gouli et al., 2004; Herl et al., 1999;

Kumaran & Sankar, 2013; Liu, 2010; Pirnay-Dummer et al., 2010). Most of these concept-mapping tools contain three components: a concept map task, a task response and an evaluation system (Ruiz-Primo & Shavelson, 1996). The major concept map tasks may be: (a) fill-in-a-concept-map where the concept map structure, the node terms and/ or the linking phrases are provided, and a student must choose the provided node terms and/ or linking phrases to fill the map; (b) construct-a-concept-map where the concept map structure is not provided, and the node terms and the linking phrases are provided partially, totally or not at all; a student must decide the concept map structure and its node terms as well as the linking phrases (Lukasenko & Anohina-Naumeca, 2010); and (c) a combination of the two. The major scoring methods may be: (a) referent-free method where student maps are scored with a rubric; (b) referent-based method where student maps are scored by comparing to expert ones (Chung et al., 2006); and (c) a combination of the two.

The existing computer-based assessment tools based on concept maps usually employ one or two types of the concept map tasks, as well as one or two scoring methods. For example, in Liu's research (2010), only one construct-a-concept-map task and one scoring method were used. Another question is raised here: why not give more options for instructors to choose from different concept map tasks and corresponding scoring methods, so as to facilitate their work and help evaluate different types of knowledge for their students with one single assessment tool based on concept maps?

Statement of the Problem

Although the research results have shown that the abovementioned two scoring methods (referent-free method and referent-based method) are broadly used, they focus only on scoring students' concept map components like counting the number of valid nodes, valid crosslinks,

level of hierarchy and examples, or comparing the student concept maps with those of experts, neither of them pay attention to the different importance of propositions of concept maps, assuming that all of the propositions are equally important (Chang et al., 2005; Lin et al., 2002). However, the different propositions might have different degrees of importance from the instructors' perspectives when they score students' concept maps. Weighted concept maps were created to solve that problem by assigning different weights to the linking phrases for scoring the degree of importance of different propositions in students' concept maps (Chang et al., 2005; Lin et al., 2002; Rye & Rubba; 2002). Compared to the original non-weighting approaches like the referent-free method and referent-based method, the weighting approach, acting as another scoring means, can help provide a quantitative analysis for assessing students' concept maps (Anohina-Naumeca et al., 2011; Chang et al., 2005; Lin et al., 2002; Mislevy & Gitomer, 1995; Wu et al., 2012). However, according to the literature review, few existing computer-based assessment tools based on concept maps integrate the weighting approach and non-weighting approach together, so as to give more options for instructors to score appropriately.

Scholars agree that concept maps can be utilized for the assessment of students' knowledge, but knowledge has different types; few existing computer-based assessment tools provide different types of concept map tasks together for instructors to choose from to assess the different types of student knowledge. In this case, it is hard for instructors to get a whole picture of their students' types of knowledge and assess them. This study aims to provide different concept map tasks in a knowledge assessment system for assessing students' various types of knowledge, and to employ the knowledge terminology defined in Anderson and colleague's revision of Bloom's Taxonomy (2001) for knowledge assessment, including factual knowledge, conceptual knowledge, procedural knowledge and metacognitive knowledge. To be specific, the

concept maps visualize and assess knowledge of basic elements and specific details, which can be described as factual knowledge; the concept maps visualize and assess knowledge of interrelationships and connections of basic elements at a higher level of abstractness, which can be described as conceptual knowledge; procedural knowledge can be measured using a series of chain-like concept maps representing knowledge of procedures to assess (Petrovic et al., 2013). The metacognitive knowledge concerns the knowledge of general cognition and one's own cognition; this type of knowledge contains three categories: person, task, and strategy (Anderson et al., 2001; Flavell, 1979). Using concept maps to access students' metacognitive knowledge is not included in this study, but is designated for future research.

According to the literature review, few existing assessment tools integrate the two differential weighting approaches for scoring students' different types of knowledge based on concept maps. The existing assessment tools are mainly used for the assessment of one type of knowledge without clarifying different types of knowledge; they do not provide more options for instructors to assign different concept map tasks to students for assessing corresponding kinds of knowledge. No existing computer-based tool specializes in knowledge assessment based on concept maps and differential weighting approaches, using the clear knowledge type definition in Anderson and colleague's revision of Bloom's taxonomy (2001). Thus, it is important to develop a knowledge assessment system for assessing students' different types of knowledge defined in the revision of Bloom's Taxonomy (Anderson et al., 2001), based on concept maps and the two differential weighting approaches.

Purpose of the Study

The purpose of the study was to design and develop a knowledge assessment system (KAS) for assessing students' different types of knowledge, as defined in the revision of

Bloom's Taxonomy (Anderson et al., 2001). Ideally, the system would be based on concept maps and would employ two differential weighting approaches. A literature review showed that although a myriad of assessment tools based on concept maps had been developed for different purposes, few tools had been specifically developed to employ a weighting and non-weighting approach together to assess the different types of knowledge defined in the revision of Bloom's Taxonomy (Anderson et al., 2001).

In this study, the researcher explored whether both a non-weighting approach and an optional weighting approach could be incorporated into a single knowledge assessment system based on concept maps, used the system for the assessment of the different types of knowledge defined in the revision of Bloom's Taxonomy (Anderson et al., 2001), and determined what overall design of concept map tasks and scoring approaches within one assessment tool could help provide a useful knowledge assessment for both instructors and students. In addition, detailed documentation of developed procedures and strategies was maintained and should benefit the future development of similar knowledge assessment tools in the instructional technology field.

Importance of the Study

According to the review of relevant literature, no researcher has made an attempt to design and develop a knowledge assessment system based on concept maps that also incorporated both a non-weighting approach and weighting approach for assessing different types of knowledge as defined in the revision of Bloom's Taxonomy (Anderson et al., 2001). In addition to addressing this need, this study also overcomes other weaknesses of assessment tools based on concept maps such as (a) eliminating the assumption of equal degrees of importance of any propositions when scoring a student concept map (Fisher, 2000; Liu, 2010; Novak & Cañas,

2006); (b) reducing the degree of inflexibility associated with current scoring methods using a single assessment approach (Chang et al., 2005; Kumaran & Sankar, 2013; Lukasenko & Anohina-Naumeca, 2010; Novak & Gowin, 1984); (c) automating the scoring process and generating a timely knowledge assessment report for both formative and summative assessment purposes, rather than only for formative assessment (Beaudry & Wilson, 2009; Conlon, 2006; Trumpower & Sarwar, 2010); and (d) expanding the assessment of limited types of knowledge or general knowledge based on concept maps (Cline, Brewster, & Fell, 2010; Gouli et al., 2004; Grundspenkis, 2011). This research extends the present literature by describing and analyzing the developmental process employed to create a knowledge assessment system based on concept maps.

Organization of the study

This study began with a review of relevant literature to investigate the possible need for a knowledge assessment system based on concept maps. Based on the results of the literature review, a decision was made to use a design and development approach (Richey & Klein, 2007) and a general software system design model (Sommerville, 2009) to guide the design and development of the Knowledge Assessment System. After an initial system was designed and developed, formative evaluations consisting of two one-to-one evaluations and a pilot test were conducted for the purpose of revising and improving the system in terms of its user interface and system functionality. Following revisions based on the formative evaluations, a summative evaluation including a small-group evaluation and a subject-matter expert review was conducted to reveal the student user's and instructor user's or expert user's perspectives of the system. The information for this process is presented in the following chapters.

Chapter 1 of this document presents the background information of the study, the need for the study, the purpose of the study and the importance of the study. Chapter 2 includes a review of the literature related to this study, which has five sections. The first section is an overview of concept maps, which focuses on introducing the typical use of concept maps and their elements and structures, as well as the weighted concept maps. The second section is an overview of knowledge assessment, which includes the introduction of types of knowledge, Bloom's Taxonomy for knowledge assessment, and a revision of Bloom's Taxonomy for knowledge assessment. The third section deals with knowledge assessment based on concept maps, which includes the theoretical underpinnings, assessment tasks based on concept maps, scoring methods, and how concept maps can be used for knowledge assessment. The fourth section is about the current computer-based assessment systems based on concept maps; five typical existing computer-based assessment systems are introduced and their strong points and possible improvements summarized. The fifth section is the overview of software system architecture. Chapter 3 focuses on the design, development and evaluation of the knowledge assessment system. Chapter 4 concentrates on the results of the research. Chapter 5 discusses the research results, the contributions of the study, the lessons learned and the limitations and possibilities for future research.

Chapter 2: Literature Review

The literature review includes five main sections. The first section introduces the typical uses of concept maps and their elements and structures, as well as the weighted concept maps. The second section includes the overview of knowledge assessment, types of knowledge, knowledge assessment based on Bloom's Taxonomy, and knowledge assessment based on a revision of Bloom's Taxonomy. The third section focuses on discussing how knowledge assessment can be based on concept maps, including the discussion of the theoretical underpinnings, concept map tasks, scoring methods and how concept maps can be used for assessing knowledge. The fourth section analyzes the functionalities and features of five existing assessment systems based on concept maps and summarizes their advantages, weaknesses and possible improvements. The fifth section provides an overview of software system architecture.

Overview of Concept Maps

Novak and colleagues formalized Ausubel's learning theory (1968) into the concept map structure made up of nodes and links (Novak, 1990; Novak & Cañas, 2006; Novak & Gowin, 1984), and posited that concept maps could help visually express a student's cognitive structure as well as demonstrate what the student already knows (Novak & Gowin, 1984). Concept maps contain concepts and relationships. The concepts are typically located in boxes or circles, and the relationships demonstrating the connections of two concepts, are usually labeled as linking phrases on directional linking lines (Novak & Cañas, 2006, 2008). Tony Buzan, a scholar from the UK, presented the idea of mind map almost at the same time as Novak (Tony & Barry, 1996). Although some scholars like Eppler (2006) discussed the little difference between concept maps and mind maps and concluded that these two maps could be used complementarily for teaching and learning, mind maps were thought of as another type of concept maps in this study

for its node-link-information-visualization characteristics. Other forms of information visualization with node-link characteristics, such as topic maps and knowledge maps, are also regarded as types of concept maps in this study.

Typical Uses of Concept Maps

The original use of concept maps was to demonstrate changes in learning of individual students over time by Novak and colleagues (Novak & Cañas, 2006; Novak et al., 1983), which was on the basis of Ausubel's (1968) Assimilation Theory of Cognitive Learning. Later on, concept maps were found to be useful to represent knowledge and organize and understand new subject matter in any discipline, as well as revealing the individual student's conceptual change (Novak & Cañas, 2006; Novak & Gowin, 1984). Concept maps were also used as tools for assisting students in recognizing and modifying their mistakes in knowledge structures (Feldsine, 1983; Novak & Cañas, 2008).

For instructors, using concept maps can help them be more effective in the hierarchical management of superordinate and subordinate concepts in curriculum design (Novak, 1990, 2010). Concept maps can also assist instructors in seeing part of the expressions of their students' creative thinking (Novak & Gowin, 1984), as well as help instructors evaluate their students' misconceptions and missing concepts (Amadieu et al., 2009; Fisher, 2000; Novak & Cañas, 2006). In fact, concept maps have been used as creativity tools (Plotnick, 1997), hypertext design tools (Botafogo, Rivlin, & Schneiderman, 1992), communication tools (Roth & Roychoudhury, 1993), learning tools (Novak & Gowin, 1984), instructional tools (Novak, 1990; Willerman & Mac Harg, 1991), and assessment tools (Chang et al., 2005; Fisher, 2000; Gouli et al., 2003; Lee et al., 2015; 2010; Liu, 2010; Novak & Gowin, 1984; Petrovic et al., 2013; Ruiz-Primo & Shavelson 1996; Su & Wang) for different purposes in different situations.

Plotnick (1997) summarized that there were five typical uses of concept mapping: (a) generating ideas like brainstorming, (b) scheming complicated structures, (c) communicating sophisticated theories, (d) facilitating learning, and (e) evaluating learning.

Elements of Concept Maps

A typical concept map contains: nodes or concepts, directional linking lines and linking phrases. Usually, the nodes or concepts are enclosed in boxes, circles or other shapes; the directional linking lines can be one-way lines or two-way lines connecting different nodes; the linking phrases on the directional linking lines indicate the relationships between two nodes, and the directions of the linking lines display the directions of the relationships of the two nodes (Novak et al., 1983). Two concepts connected with a linking phrase through a directional linking line form a meaningful statement. A combination of node-linking phrase-node is seen as a basic meaningful unit in a concept map, which is regarded as a proposition (Novak et al., 1983; Novak, 2010).

Structures of Concept Maps

Concept maps have different structures. For instance, there exist spider-like concept maps, hierarchical concept maps, flow chart concept maps and semantic network concept maps. Although Novak and colleagues (1983) proposed hierarchical structures in concept maps, Ruiz-Primo and Shavelson (1996) posited that the structures of concept were related to the content of the concept maps and it was unnecessary to restrict the structure of a concept map to hierarchy. For example, compared to hierarchical concept maps, a network concept map is better at showing a semantic relation network (Ruiz-Primo & Shavelson, 1996). In fact, Kinchin (2000) proposed three types of concept mapping structures: spoke concept map, chain concept map, and

net concept map. Yin et al. (2005) posited that the chain type of concept map could be a linear chain, circular chain or tree chain based on their students' responses in an experiment. Summarizing these scholars' perspectives, the structures of concept maps can be line, circle, spoke or hub, tree, and net or network (Yin et al., 2005).

Weighted Concept Maps

Weighted concept maps were termed for assessment purposes through assigning different weights to different propositions in a concept map (Lin et al., 2002); the weights could be used to represent the degree of importance of the propositions. In fact, Novak and Gowin (1984) originally assigned different weights to concept maps to obtain a total score in a scoring system based upon concept maps. For example, they categorized the valid components of a student concept map as valid nodes, valid branches, valid cross-links and valid levels of hierarchy, then assigned different weights to these categories for calculating a total score. However, Novak and colleagues focused the weights only on those different categories rather than the different propositions in terms of the degree of their importance. In addition, the weights they assigned were restricted to the valid components in hierarchical concept maps.

Currently, the assessment based on concept maps is achieved through the comparison between a student-created concept map and an expert map. This method concentrates on the correctness and completeness of each proposition by comparing the quality of the propositions in student-created concept maps with those found in experts' concept maps. This method has been proved to be reliable and valid by various scholars (Herl et al., 1999; McClure et al., 1999; Rye & Rubba; 2002). However, this scoring method does not take into account the degree of importance of various propositions, and assumes that all of the propositions in a concept map are equally important, which may not be accurate. Weighted concept maps were originally created to

allow instructors to assign different weights to different propositions in terms of their importance for obtaining a more accurate assessment result when assessing a student-created map (Chang et al., 2005; Lin et al., 2002; Rye & Rubba; 2002). Gouli and colleagues (2005) assigned the weights to each proposition and each error category (e.g., the proposition which appeared in the expert's concept map, but was missing in a student's map), to score the propositions of student-created maps and evaluate the student's knowledge level. The research results showed that weighted concept maps could effectively help reveal the students' learning states and display to what degree they had learnt a proposition. In fact, the weighted concept map was initially created as an assessment criterion for scoring the degree of importance of different propositions in student concept maps. Therefore, it can be seen as a kind of scoring method based on concept maps.

Overview of Knowledge Assessment

Knowledge assessment is an essential part of education (Lukashenko & Anohina, 2009), and it is based on identifying all possible knowledge states of students. Knowledge states indicate various aspects of students' current understanding of domain-knowledge and represent student capabilities for some kind of problem solving (Doignon & Falmagne, 1985, 1988; Falmagne et al., 2006). For assessing student knowledge, the task of the assessor is to uncover the particular state of the student being assessed and to label "what the student can do" and "what the student is ready to learn" (Falmagne et al., 2006, p.1).

Types of Knowledge

Several types of knowledge were introduced and classified by different scholars. For example, Collins (2010) discussed tacit knowledge and explicit knowledge. Tacit knowledge was deeply related to personal experience and practice and could be seen as subjective knowledge,

while explicit knowledge could come from dialoging with others or demonstration and was regarded as objective knowledge. One main difference between these two types of knowledge was that explicit knowledge was very easy to explain to others while tacit knowledge was relatively hard to explain to others. Alexander and Judy (1988) distinguished three types of knowledge: declarative knowledge, procedural knowledge and conditional knowledge. Declarative knowledge was about factual information; procedural knowledge was about compiling the declarative knowledge into functional parts with particular approaches; and conditional knowledge was about understanding when, where and why to use declarative knowledge or particular procedures. However, Jonassen, Beissner, and Yacci (1993) claimed that there existed another knowledge type – structural knowledge, which could be seen as an intermediate knowledge type between declarative and procedural knowledge allowing for transformation of declarative knowledge into procedural knowledge with particular strategies.

In addition, according to the perspective of cognitive science, four types of knowledge – factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge – were classified according to a taxonomy of educational objectives (Anderson et al., 2001). Factual knowledge means the knowledge of particular details and basic components; conceptual knowledge is the knowledge of relationships or correlations of basic components; procedural knowledge consists of the knowledge of rules, algorithms, and procedures; and metacognitive knowledge is the knowledge about general cognition and one's own cognition. Factual knowledge and conceptual knowledge are about knowing-what, and the procedural knowledge and metacognitive knowledge are about knowing-how (Anderson et al., 2001; Mayer, 2002).

Although there are different dimensions for expressing the concept of knowledge, there is no most appropriate type of knowledge definition for all learning circumstances. In this study, the knowledge type definitions in the cognitive domain are chosen for use since they provide distinct categories along with learning objectives, which can be used for knowledge assessment purposes.

Bloom's Taxonomy for Knowledge Assessment

For assessment purposes, instructors need to identify the students' current learning levels or states and determine whether the students have achieved the instructional objectives (Popham & Popham, 2005). Bloom and colleagues (1956) classified six levels of learning objectives in the cognitive domain and organized them hierarchically (see Figure 1).
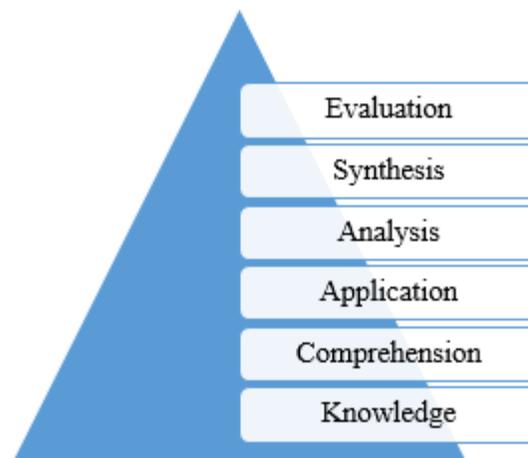
Figure 1. Six levels of cognitive domain in Bloom's Taxonomy (Bloom, 1956)

Beside using the taxonomy as a means for designing and developing course objectives, instructors can also use the cognitive process proposed in Bloom's Taxonomy as a guide to create and revise assessments so that they are consistent with what they have taught (Halawi, McCarthy, & Pires, 2009; Kastberg, 2003). In fact, the most common use of this taxonomy is to

categorize instructional objectives and corresponding assessment items across the spectrum of the six categories; it is both a pedagogical tool and a measurement tool to some extent (Anderson et al., 2001; Krathwohl, 2002).

However, in the above figure (see Figure 1), *Knowledge* was regarded as the lowest level for indicating memorization of basic information, which omitted other levels of knowledge and was seen as a weakness. This weakness was corrected by introducing the knowledge dimensions in the Revised Bloom's Taxonomy (Anderson et al., 2001).

Revised Bloom's Taxonomy for Knowledge Assessment

The major weaknesses of Bloom's Taxonomy of cognitive domain include: assuming the cognitive processes to be arranged on a sole dimension, from simple to complicated; presuming no overlapping of the six categories of instructional objectives (Amer, 2006; Anderson et al., 2001). The Revised Bloom's Taxonomy overcomes the above weaknesses and affords a much more concise graphical demonstration for classifying educational objectives, activities and assessments (Krathwohl, 2002).

In the revised taxonomy, knowledge is treated as a separate dimension and classified into four types of knowledge: factual, conceptual, procedural and metacognitive, ranging from the concrete to the abstract. Another dimension of the revised taxonomy is the cognitive process, which is akin to the original cognitive procedure of Bloom Taxonomy but which uses a series of verbs to indicate the process (Anderson, Krathwohl, & Bloom, 2005; Forehand, 2010). The cognitive process dimension consists of six categories: remember, understand, apply, analyze, evaluate, and create.

The revised cognitive taxonomy changed the conceptualization of Bloom's original one-dimensional cognitive taxonomy into a two-dimensional one, and subdivided the knowledge concept into four types of knowledge, which offered a more clearly differentiated concept of knowledge to help instructors with a promising guide to design what-to-evaluate and how-to-evaluate problems for assessing students' knowledge (Forehand, 2010; Popham & Popham, 2005). For instance, Milman (2014) used the Revised Bloom's Taxonomy as a framework to design online discussion questions for assessment purposes. In this study, the four types of knowledge defined in the Revised Bloom's Taxonomy are used when evaluating students' different types of knowledge within a knowledge assessment system based on concept maps.

Knowledge Assessment Based on Concept Maps

Concept mapping can be used as a means for representation and measurement of students' knowledge (Croasdell & Urbaczewski, 2003); concept mapping can also inspire students to externalize their actual states of knowledge, as well as allow the students to demonstrate their high-level cognitive abilities according to the Revised Bloom's Taxonomy, particularly when the students offer the correct or most appropriate propositions in their concept maps (Lukashenko & Anohina, 2009; Novak & Cañas, 2006; Petrovic et al., 2013). In addition, concept mapping can help check the students' understanding of the relationships of concepts they have learnt, rather than some degree of recall of isolated facts. For example, Ruiz-Primo (2004) posited that concept mapping could be used to assess the vital facets of students' declarative knowledge structure. The research efforts of Chung et al. (2006) also indicated that concept maps could be employed to evaluate students' procedural knowledge and declarative knowledge.

Compared to traditional tests using true-false or multiple-choice questions, concept mapping can effectively help present students' understanding of the direct interconnections among many concepts and reveal how they organize their knowledge, along with demonstrating their creativity when incorporating important propositions into a concept map (Luckie et al., 2003, 2008; Popham & Popham, 2005).

Theoretical Underpinnings

As a pedagogical tool, concept maps were developed by Novak and colleagues for representing students' conceptual understanding in the 1970s based on Ausubel's Assimilation Theory (Ausubel, 1968). This theory emphasized that prior knowledge had the most influence on a student's learning. Novak and colleagues focused on how to help incorporate new knowledge into students' conceptual models through connecting concepts (Novak and Gowin 1984; Stoddart et al., 2000). Three key points can be extracted from Novak and colleague's research efforts on concept maps: new learning rests upon prior related concepts and propositions; organizing the cognitive structure in a hierarchy and putting the general concepts at the top and placing specific concepts under general ones; and once meaningful learning occurred, new concepts could be much more easily incorporated with existing relevant concepts or propositions (Novak & Cañas, 2006).

According to Novak's perspectives, meaningful learning benefits most in building knowledge structure, and concept maps can work well as a knowledge representation tool which can help students learn meaningfully, as well as facilitate the organization of a learner's knowledge and creation of new knowledge.

Besides Ausubel's Assimilation Theory, Deese's Associationist and Memory Theory (1965) stressed that cognitive structure could be regarded as a series of concepts and their mutual relations (Ruiz-Primo & Shavelson, 1996), and posited that a set of concepts in a network structure could also provide accommodations in a hierarchical relationship (Ruiz-Primo, 2004). Ausubel's Assimilation Theory put emphasis on the hierarchically conceptual structure, while Deese's Associationist and Memory Theory focused on a network of conceptual structure. These two theories can be used together to interpret how concept maps elicit students' knowledge structure in a domain, and how these concepts are interrelated in that domain (Ruiz-Primo & Shavelson, 1996; Ruiz-Primo, 2004).

In addition, constructivist epistemology claims that the learning of new knowledge is a personal endeavor. To be specific, when a new concept is learned, this concept is usually structured by the student into his or her mind or conceptual model (Sheckley & Bell, 2006). A student can develop his or her own conceptual model based upon the association with the knowledge he or she has already obtained (Popova-Gonci, 2013). Cognitive psychologists also posit that the internal representations of knowledge in human's brain resemble networks of ideas, which are similar to network concept maps that are structured (Sternberg, Sternberg, & Mio, 2012); the more relationships that are established between the new concepts and a learner's conceptual model, the better the understanding that the learner obtains (Derbentseva, Safayeni, & Cañas, 2007; Williams, 1998).

Synthesizing the different scholarly perspectives, it can be seen that concept mapping, acting as a means of knowledge assessment, can employ several related learning theories to interpret well together, although these scholars have different angles.

Assessment Task Based on Concept Maps

Shavelson, Lang and Lewin (1994) summarized that there were at least 128 diverse types of concept map tasks based on how much information was provided to students. Ruiz-Primo and Shavelson (1996) posited that a concept map task included three major components: concept map task requirements, concept map structures and concept map task restrictions. Concept map task requirements were the demands placed upon the students when they undertook the task; concept map task restrictions meant the constraints for the task; and concept map structures referred to how to organize the concept map based on the task requirements and constraints.

Lukasenko and Anohina-Naumeca (2010) reviewed multiple studies and summarized that two main kinds of concept maps could be employed for assessment purposes: (a) fill-in-a-concept-map where the concept map structure, the node terms and/ or the linking phrases are provided, and a student must choose the provided node terms and/ or linking phrases to fill the map, and (b) construct-a-concept-map where the concept map structure is not provided, and the node terms and the linking phrases are provided partially, totally or not at all; a student must decide on the concept map structure and its node terms as well as the linking phrases.

To be specific, the concept map tasks can be (a) fill-in-a-concept-map with provided total or partial nodes or not at all, (b) fill-in-a-concept-map with provided total or partial linking phrases or not at all, (c) construct-a-concept-map with provided total or partial or none of node terms and linking phrases, and (d) construct-a-concept-map with complete, partial or none of the structure provided. In addition, some concept map tasks can be mixed with distracters like similar but incorrect node terms or linking phrases. Depending on how much information was provided to students, the concept map tasks could have different formats (Anohina-Naumeca & Graudina, 2012). For instance, Lukasenko and Anohina-Naumeca (2010) designed six types of

concept maps in an online experiment: (a) fill-in-the-map with provided whole node terms; (b) fill-in-the-map with provided partial node terms; (c) fill-in-the-map with provided whole node terms and partial linking phrases; (d) fill-in-the-map with provided partial node terms and partial linking phrases; (e) construct-the-map with whole node terms and linking phrases; and (f) construct-the-map with partial node terms and partial linking phrases. Strautmane (2012) provided an overview of the various concept map tasks based on what types of information were given to the students. For example, the given information could be: (a) a complete or partial structure; (b) complete, partial or empty node terms and linking phrases; and (c) distracters.

Sometimes different names were used by different researchers to denote these concept map tasks. For instance, Herl et al. (1999) categorized two types of concept map tasks: open concept map tasks and closed concept map tasks. The open concept map tasks indicated that the students needed to construct their own nodes and links without provided lists of information, which was very similar to the construct-a-concept-map task; the closed concept map tasks meant that the students could choose from the provided information such as node terms or linking phrases to complete the task, which was akin to the fill-in-a-concept-map task or some form of construct-a-concept-map task. In addition, Ruiz-Primo (2004) claimed that the concept maps could be grouped as high-directed concept map tasks and low-directed concept map tasks. The high-directed concept map tasks entailed providing lists of information such as node terms or linking phrases to students when they completed a concept map task; the low-directed concept map tasks provided limited information to students when they created their concept maps. In this sense, the fill-in-a-concept-map task may be seen as a type of high-directed concept map task and the construct-a-concept-map task may be regarded as a kind of low-directed concept map task.

Different tasks based on concept maps have different purposes and reflect different information about student knowledge. For example, the high-directed concept map tasks put various cognitive requirements on students compared to the low-directed ones, and the high-directed concept map tasks may activate the students' domain-knowledge more, while the low-directed concept map task may support the students' demonstration of the structures of their knowledge to a greater extent (Gouli et al., 2003). In terms of demonstrating the differences in knowledge structures of students, the construct-a-concept-map task is more efficient than the fill-in-a-concept-map task (Ruiz-Primo et al., 2001). In addition, the research efforts of Yin et al. (2005) indicated that the task of construct-a-concept-map-with-created-linking-phrases was more effective than the task of construct-a-concept-map-with-selected-linking-phrases for uncovering students' misunderstandings or revealing partial knowledge. In fact, no one concept map task could be most appropriate for all assessment purposes (Strautmane, 2012).

Scoring Methods

The kinds of concept map scoring method can be used depend to some extent on instructors' preferences, domain knowledge aspects and concept map tasks (Brewster & Fell, 2010; Novak & Gowin, 1984). Novak (1983) used a teacher-developed scoring rubric to assess students' concept maps, which included counting the number of correct nodes, appropriate cross-links, branches and hierarchy levels. Ruiz-Primo and Shavelson (1996) proposed three scoring strategies: (a) scoring the constituent parts of a student-created concept map; (b) comparing a student-created concept map with an expert one; and (c) combining the two. According to Ruiz-Primo and Shavelson, scoring the constituent parts of students' concept maps focused on three components – propositions, hierarchy levels and branches, which was very similar to the method that Novak used; comparing a student-created concept map with an expert one assumed that

there existed a concept map acting as a criterion which ideally echoed the structures of students' knowledge.

Chung et al. (2006) asserted that two scoring methods could be used: referent-free approach and referent-based approach. The referent-free approach put emphasis on scoring a student-created concept map with a rubric, while the referent-based approach stressed scoring a student-created concept map by comparing it with an expert one. In particular, the referent-based approach has been used in several studies and the research results have shown that it is reliable and valid for assessing student-created concept maps (Herl et al., 1999; McClure et al., 1999; Rye & Rubba; 2002).

However, the referent-based method has some limitations. For example, a student-created concept map may be evaluated by comparing it to a criterion map in terms of proposition-by-proposition, without taking the concept map structure into account (Chung et al., 2002). But Liu (2010) posited that comparing the structure of a student concept map to an expert one was very hard to auto-assess when using computer-based assessment tools. In addition, the method did not consider the hidden meanings of the relationships between the nodes. For instance, in some other cases, the "hidden" relationships existing in students' concept maps were derivations of relationships presented in expert ones and could therefore be recognized as correct (Anohina-Naumeca, Grundspenkis, & Strautmane, 2011; Grundspenkis & Strautmane, 2009). For example, if the standard linking phrase was "is a," which indicated that a relationship between a class and its subclass in an expert concept map may have a "hidden" relationship like "has" or "kind of."

Another limitation was that all of the relationships in students' concept maps were assumed to be equally important; it was hard to score the quality of propositions without some quantitative methods. Actually, the degree of importance of each node and relationship was

different. Some nodes and relationships in students' concept maps might have more or less importance than others. Without assigning weights to different relationships between the nodes, instructors could not quantitatively determine to what extent the students had mastered the related knowledge that the propositions conveyed. To address this kind of problem, Lin et al. (2002) originally proposed using weighted concept maps in one research study for assessment purposes; Chang et al. (2005) assigned different weights to different propositions in an expert map when employing it as a criterion for scoring students' propositions; Gouli and colleagues (2005) conducted another research study by assigning weights to each concept, proposition and each error category (e.g., the misspelling proposition) to score students' concept maps and subsequently evaluate their knowledge levels. The results showed that employing the weighted concept map could effectively help instructors determine their students' knowledge states and to what extent their students had grasped the related knowledge that the propositions conveyed.

To synthesize these different scholars' perspectives, it can be seen that for assessing students' concept maps, the valid nodes, linking phrases, propositions and appropriate branches should be counted; and, ideally, each node, relationship and proposition should be weighted to show their different degrees of importance when using experts' concept maps as a criterion. In addition, the "hidden" relationship or "hidden" concept can be recognized as correct and should have the same weight as the standard one in experts' concept maps. For the missing components or misconceptions in students' concept maps, they also need to be considered when scoring student-created concept maps because they may contribute to understanding the overall knowledge states of students.

How Concept Maps Can Be Used for Assessing Knowledge

Novak and colleagues originally used concept maps to evaluate the changes in students'

understanding of scientific conceptions in the 1970s. From that time on, a myriad of scholars have explored concept maps for assessment purposes. For instance, Surber and Smith (1981) employed concept maps to inspect students' misconceptions in a domain. Williams (1998) proposed that concept mapping could be used to evaluate the organization of a student's knowledge as well the student's conceptual understanding of a domain knowledge.

In fact, as a knowledge representation method, concept maps have been used as an alternative knowledge assessment tool (Anohina-Naumeca et al., 2011; Novak & Cañas, 2006). For students, concept mapping can be used to self-assess their knowledge after they study a learning material; for instructors, concept mapping can be employed to make a diagnosis of their students' knowledge structures and misunderstandings as well as missing concepts (Fisher, 2000; Gouli et al., 2005; Segalàs et al., 2008). For example, the CmapTools software based on concept maps developed by Novak and colleagues could help demonstrate students' concept maps and the experts' concept maps at the same interface, and provide a list of concepts and propositions as well as the difference between the student concept maps and the expert ones. This made it easy to evaluate the quality of student-created concept maps and assess the students' knowledge that the concept maps conveyed.

Assessment Tools Based on Concept Maps

A number of scholars in various fields have investigated computer-based tools based on concept maps for assessment purposes (Anohina-Naumeca et al., 2011; Cañas et al., 2004; Chang et al., 2005; Cline et al., 2010; Fisher, 1992, 2000; Gouli et al., 2004, 2006; Grundspenkis, 2011; Herl et al., 1999; Kumaran & Sankar, 2013; Liu, 2010; Pirnay-Dummer et al., 2010). The following section focuses on the review of five typical assessment tools based on concept maps.

CmapTools

The CmapTools (Cañas et al., 2004) software which was developed by Novak and

colleagues at the Florida Institute for Human and Machine Cognition (IHMC), allowed users to

create and share their concept maps. It has a client-server architecture, and it permits anyone to

download the client software and install it for free. It supports asynchronous or synchronous

collaboration in the construction of concept maps, as well as comments and peer review of those

concept maps (Cañas et al., 2004). This tool lacks an automatic assessing function for generating

an assessment report, but it has a recorder feature that records and plays back the process of

concept map creation. This feature can help instructors review and compare student-created

concept maps with the expert ones and provide feedback. In addition, the "Compare concept

maps" module of this tool allows for comparing a student concept map with an expert one, or for

comparing the new version of a student-created concept map with a previous version. The

characteristics of CmapTools are displayed in Table 1.

Table 1. *The Characteristics of CmapTools*

Characteristics	Descriptions
User interface	One main area with sub panel is provided; buttons are easy to recognize.
Operation of concept map	Click button with drag-and-drop.
Node and link format	Icon and color can be set.
Scoring approach	Allows for comparing students' concept maps with expert ones based on different options. No automatic assessment.
Feedback format	Provide comments.
Assessment report	No
Student response format	Construct concept maps freely.

Task creation and assignment	Limited.
System architecture	Client-Server

Concept Map Assessment System (CMAS)

The Concept Map Assessment System (CMAS) was originally created by Gouli and colleagues (2004). It is a web-based learning and assessment system based on concept maps.

The concept mapping tasks in this system are diverse and allows users to construct their concept maps freely or partially. The feedback is provided based on specific common errors identified in students' concept maps, as well as comparing them with the expert maps. This tool focuses on scoring the links by inspecting the correctness and entirety of the propositions in student-created concept maps; it also examines the missing propositions in student-created concept maps. One strong point is that the tool provides a quantitative analysis of the assessment result by evaluating learner's concept maps based on the weights assigned to different propositions; these weights echo the degree of importance of the propositions. The weakness is that the tool does not support assessing different types of knowledge and provides a limited authoring function and report function. The characteristics of CMAS are summarized in Table 2.

Table 2. *The Characteristics of Concept Map Assessment System (CMAS)*

Characteristics	Descriptions
User interface	Menus, buttons and symbol palette are provided.
Operation of concept map	Click menu and button.
Node and link format	Rectangles, ovals and links are provided.
Scoring approach	Automatic. Support instructor's assessment and peer assessment, comparison with expert concept map. Adopt weighted concept map as a scoring method.

Feedback format	Dialogue feedback with text and graphics.
Assessment report	For general knowledge only.
Student response format	Freely or partially construct a concept map; extend or correct a given concept map.
Task creation and assignment	Provide a range of concept map tasks with limited authoring function.
System architecture	Browser-Server

Assessment Agent Tool Based on Concept Maps (AATOOL)

This online concept map tool based on agent technology was developed by Jianhua Liu and colleagues (2010), and it aimed to provide a large-scale assessment through online concept mapping. It is web-based and was created using ColdFusion and Flash technologies. The task format requires students to create their concept maps based on the given node terms and linking phrases, along with several distracters. The concept maps are created by using a drag-and-drop procedure. The scoring method employed by this tool is the comparison of student propositions with the expert proposition database, which is maintained by the instructors. The drawback is that the tool only supports limited task formats. The characteristics of AATOOL are presented in Table 3.

Table 3. *The Characteristics of Assessment Agent Tool Based on Concept Map (AATOOL)*

Characteristics	Descriptions
User interface	Menus, buttons are provided.
Operation of concept map	Click menu and button, with drag-and-drop.
Node and link format	Ovals and links are provided.
Scoring approach	Automatic. Compares the student concept map with the criterion proposition database.

Feedback format	Provide feedback based on the reporting function. Provide comments.
Assessment report	A table lists correct, wrong, different and missing propositions only for conceptual understanding.
Student response format	Partially construct a map, with the given node terms and links as well as distracters.
Task creation and assignment	Limited task formats.
System architecture	Browser-Server

Weighted Concept Map Tool (WCMT)

This concept map tool was revised from a research outcome by Chang, Sung and Chen (2001) and was used for evaluating the empirical student-created concept maps by Chang and colleagues in 2005. The tool assigned weights to the relationship links between the nodes and integrated weighted concept maps into the assessment criteria to help provide a quantitative analysis to display the various learning states of students. The scholars proposed that the learning states contained: (a) a proposition was learned; (b) a proposition was partially learned; (c) a proposition was not learned; and (d) a proposition was misunderstood (Chang et al., 2005). The shortcoming of the tool was that it did not provide a complete report function and the task creation and assignment was limited. The characteristics of WCMT are displayed in Table 4.

Table 4. *The Characteristics of Weighted Concept Map Tool (WCMT)*

Characteristics	Descriptions
User interface	Menus and tool-bar are provided.
Operation of concept map	Click menu and button.
Node and link format	Rectangle and links are provided.

Scoring approach	Automatic, comparing with expert concept map and assigning weights to the relationships.
Feedback format	Immediate feedback if clicking the evaluation button.
Assessment report	Only for general knowledge with limited information.
Student response format	Partially construct a map, with provided node terms and links.
Task creation and assignment	Limited task formats.
System architecture	Browser-Server

Knowledge Map with Appraisal of Concept Weight Tool (KMACWT)

This tool was originally developed for helping primary school teachers create educational assessment properly through analyzing course material and displaying a concept weight-annotated knowledge map (Su & Wang, 2010). The research results of using KMACWT in a real online learning environment indicated that the tool had a high practical value for educational assessment, and could help teachers with their assessment work efficiently. This tool contained six components: (a) preprocessing the learning sections, (b) extracting the concepts, (c) computing the relationships between the concepts, (d) computing the weights, (e) retrieving the items, and (f) generating the knowledge map. This tool did not include the task authoring function and the automatic scoring function, but it had a concept weight computation module and adopted the weighted map for visualizing the importance of the different relationships among the concepts.

According to the reviews of the five typical tools based on concept maps, these tools provided various functionalities for the assessment purposes. Summarizing these functionalities, a new knowledge assessment tool may need to have these features: (a) user interfaces for easily

creating concept maps, (b) authoring functions for straightforwardly creating various concept map tasks, (c) multiple student response formats, (d) scoring methods for auto-assessing student maps, and (e) reporting functions for displaying student's performance (See Table 5).

Table 5. *Necessary Features for a New Knowledge Assessment Tool based on Concept Maps*

Features	Descriptions
User interface	Easy to create a concept map.
Node and link format	Ovals or other shapes are provided.
Authoring function	Allow instructors to create tasks.
Student response collection	Multiple response formats can be set and collected.
Scoring method	Automatic. Comparison with experts' concept map; counting the number of valid propositions; assigning weights to propositions; propositions assessment pool.
Reporting function	The performance of students with tables.
System architecture	Browser-Server, web-based.

Although the five typical tools based on concept maps had strong points that could be used as references for the design of the knowledge assessment system, they still had possibilities for improvement. Their strong points and improvement possibilities are summarized in Table 6. These tools mostly were used for formative assessment and aimed at improving learning and assessment through concept mapping; they concentrated on assessing the learners' conceptual knowledge or declarative knowledge. No existing systems fully take into account providing functions to assess students' different types of knowledge based on concept maps and differential weighting approaches.

Table 6. *The Strong Points and Improvement Possibilities of the Five Representative Tools*

Tool	Strong Points	Improvement Possibilities
CmapTools	Provides "Compare concept maps" module, which can use both expert concept maps and counting the number of valid nodes and propositions for scoring.	Could provide report function, extend task management function for assessing various types of knowledge, and integrate weighted concept maps.
CMAS	Provides adaptive informative feedback, integrate weighted concept maps.	Could provide more various concept map tasks for assessing various types of knowledge and improve authoring function and report function.
AATOOL	Provides most necessary functions for an assessment tool based on concept maps.	Could provide immediate feedback and more various concept mapping for assessing various types of knowledge. Could integrate weighted concept maps.
WCMT	Adopts weighted concept maps and provides immediate feedback if clicking the evaluation button.	Could provide more various concept map tasks for assessing various types of knowledge, could improve report function.
KMACWT	Provides a concept weight computation module.	Could provide more various concept map tasks for assessing various types of knowledge. Could provide automatic scoring function.

Overview of Software System Architecture

Jen and Lee (2000) claim that a software architecture is the essential organization of a software system that contains the components, the relationships of these components, and the approaches to directing software design. Software architecture is the blueprint when developing a software system and can be regarded as a high-level design of a software system; it breaks the system into subsystems and components, and describes how these subsystems and components interact with each other (McGovern, 2004; Pressman, 2010).

There exist four primary views from different stakeholders when designing a software architecture: (a) a logical view, indicating the core perspectives of the system requirements; (b) a process view, showing the interaction processes of the system at run-time, which is useful for evaluating the system quality and performance; (c) a development view, displaying how the system is modularized, which is valuable for the system manager and programmers; and (d) a physical view, presenting how to distribute the related hardware and components (Krutchen, 1995).

The software system architecture can be designed on the basis of an architectural pattern, which is a series of principles for designing a family of systems (Pressman, 2010). The widely used architectural patterns include: (a) Layered Architectural pattern, which divides the software into units called layers, and each layer groups a set of modules to provide a cohesive service; (b) Model-View-Controller (MVC) pattern, which divides a software application into three logical components: model, view and controller; (c) Client-Server Architecture (CSA) pattern, which is a distributed computing architecture and includes three elements: client, server, and request/response connector, with a two-tier CSA for simple systems and a three-tier CSA or multi-tier CSA for complicated systems; and (d) Service-Oriented Architecture (SOA) pattern, which describes a collection of loosely coupled services for supporting interoperability of distributed components running on different platforms and coded in diverse programming languages (Bass, Clements, & Kazman, 2013; Shaw & Garlan, 1996; Sommerville, 2009). The four architectural patterns have their advantages, weaknesses and constraints, which are summarized in Table 7.

Table 7. *Comparison of Four Architectural Patterns*

Pattern Name	When Used	Advantages	Weaknesses
Layered Architecture	Build new facilities on top of existing systems. Each team located in different places develops one layer of functionality.	Allow the replacement of one layer when the interface is maintained. Provide redundant facilities in each layer.	Hard to provide a clean separation between layers. May reduce system performance.
Model-View-Controller	Provide several methods to view and interact with data.	Allow the data to be changed independently of its representation. Present the same data using various ways.	May involve additional code and code complexity.
Client-Server	Access a shared database from different Locations.	Support servers to be distributed. Support one server to provide general functionalities to all clients.	Each server may be a single point of failure. Performance may be unpredictable. May exist management problems.
SOA	There exists a legacy information system that needed to be integrated seamlessly.	Support interoperability of distributed modules running on various platforms and coded in diverse programming languages, provided by different organizations.	Typically complex to build. Hard to control the evolution of independent services. Hard to provide performance guarantees.

Note. Adapted from Pressman, R. S. (2010). *Software engineering: A practitioner's approach*. New York: McGraw-Hill Higher Education; Sommerville, I. (2009). *Software engineering*. Boston: Pearson/Addison-Wesley.

Applying an architectural pattern is not an all-or-nothing proposition, since any given pattern definition is strict. In practice, it is feasible to choose to violate the design in small ways when there is a good design tradeoff. For example, the layered pattern expressly prevents the lower layers from using the upper layers directly, but there may exist some specific exceptions for the sake of improving software performance (Bass et al., 2013).

For the knowledge assessment system in this study, the three-tier Client-Server architecture was used for these reasons: (a) although the MVC pattern is useful for simplifying and managing the development of user interfaces, it does not describe how to build a scalable system infrastructure; (b) the knowledge assessment system is designed to enable any instructor to create and administrate a concept map task as well as use it to assess students' knowledge; students just need to take the concept map task with a web browser on any computer, laptop or tablet; there is no existing system or different teams to be cooperated with, so there is no need to use the layered architecture pattern; (c) there is no legacy system needed to interoperate with, and the knowledge assessment system is independent, therefore, the SOA is not needed here; and (d) compared to the two-tier CSA, which is employed for very simple client-server systems, the three-tier CSA could provide a better useful model with high loads, high reliability and high security for the knowledge assessment system (Pressman, 2010).

Overall Summary of the Literature Review

Compared to multiple-choice questions or short-answer questions, concept mapping provides another means of assessing students' knowledge. Different types of concept map tasks like fill-in-a-concept-map task and construct-a-concept-map task can be employed to evaluate different types of student knowledge. Although various scholars have conducted research related to using concept maps for assessment purpose, these scholars use diverse knowledge terminologies for their assessments. In this research, the knowledge types defined in the revision of Bloom's Taxonomy (Anderson et al., 2001) are used in the knowledge assessment system based on concept maps and two differential weighting approaches; they are factual knowledge, conceptual knowledge, procedural knowledge and metacognitive knowledge.

The referent-based method, focusing on comparing the student map with a criterion, has been used in multiple studies and the research results indicate it is valid and reliable (Herl et al., 1999; McClure et al., 1999; Rye & Rubba; 2002). However, this method does not pay attention to the degree of importance of different propositions, and assumes that all of the propositions in a student-created concept map are equally important, which is not always true in reality. Weighted concept maps were created for scoring the degree of importance of different propositions in student concept maps. Compared to the previous non-weighting approach like the referent-based method, the weighting approach could help provide meaningful quantitative analysis when assessing students' concept maps in terms of the importance of the different propositions.

The existing assessment systems based on concept maps provide similar or different functionalities, which could be used as references to design the knowledge assessment system. However, the existing tools are primarily for formative assessment without clarifying different types of knowledge. In addition, few existing concept mapping assessment systems take into account the combination of concept maps and weighted concept maps. Therefore, it is meaningful and worthwhile to develop a knowledge assessment system based on concept maps and two differential weighting approaches.

Compared to other different types of system architecture, the three-tier Client-Server architecture is appropriate for the knowledge assessment system, due to its quality attributes and the requirements and constraints of this research project.

Chapter 3: Design and Development

The purpose of the study was to design and develop a knowledge assessment system for assessing students' different types of knowledge, as defined in the revision of Bloom's Taxonomy (Anderson et al., 2001). The system was supposed to be based on concept maps and designed to employ two differential weighting approaches. This study is a product and tool research (Richey & Klein, 2007).

Research Design

This study included three phases: the design phase, development phase and evaluation phase. The design phase began with a literature review, investigating the core value of developing a knowledge assessment system based on concept maps and two differential weighting approaches. This step was followed by an analysis of the requirements of knowledge assessment tools based on concept maps, which included an examination of the kinds of user roles associated with concept maps, the types of knowledge that can be evaluated through concept mapping activities, the kinds of concept map tasks that can be used to assess corresponding knowledge, and the kinds of scoring methods that can help provide a whole picture of assessment of students' knowledge. After that, the researcher identified the system architecture, designed the components of the knowledge assessment system, and determined the detailed sub-functionalities of each component.

In the development phase, it was necessary to select a computer platform and programming language that could be used to develop the assessment system. This step was followed by the development of a proper database for the functionalities and, after that, the development of the detailed system functionalities. Finally, the user interfaces for the whole system were designed and developed.

In the evaluation phase, four types of evaluations were employed: one-to-one evaluation, pilot test, small-group evaluation and subject-matter expert review. The knowledge assessment system was improved based on the results of these four types of evaluations. The research procedure can be summarized as follows (see Table 8):

Table 8. *The Major Research Process of this Study (adapted from Liu, 2010)*

Phase	Research Activity
Literature Review	Review the researches of concept maps and weighted concept maps, and identify their features and characteristics that could be used for knowledge assessment system design.
	Review knowledge and knowledge assessment, and identify the components that can be used to design the knowledge assessment system.
	Review and analyze the studies related to concept maps used for assessment purposes in an attempt to ascertain the concept map task formats and assessing methods (differential weighting approaches) for the design of a knowledge assessment system.
	Review and analyze existing assessment systems on the basis of concept maps and weighted concept maps to summarize the necessary functionalities for the design of a knowledge assessment system.
	Review and analyze the existing software system architecture patterns and select an appropriate software architecture for the knowledge assessment system.
Design	Analyze the requirements of the knowledge assessment system.
	Design the system architecture of the knowledge assessment system.
	Design the major components and the interfaces between these components.
	Design detailed functionalities of each component.
	Design the database.
Development	Choose the appropriate technologies for the development.
	Develop the database.
	Develop the detailed system functionalities.
	Develop the user interfaces.

Evaluation	Conduct one-to-one evaluations, identify problems and improve the system.
	Conduct a pilot test, identify problems as well as improve the system.
	Conduct a small group evaluation.
	Conduct subject-matter expert evaluations.
	Collect the evaluation data, analyze these data and summarize the evaluation results for improving the system.

The Design of the Knowledge Assessment System

Sommerville (2009) presented a general model for the software system design process (see Figure 2), which was used to guide the design of the knowledge assessment system.
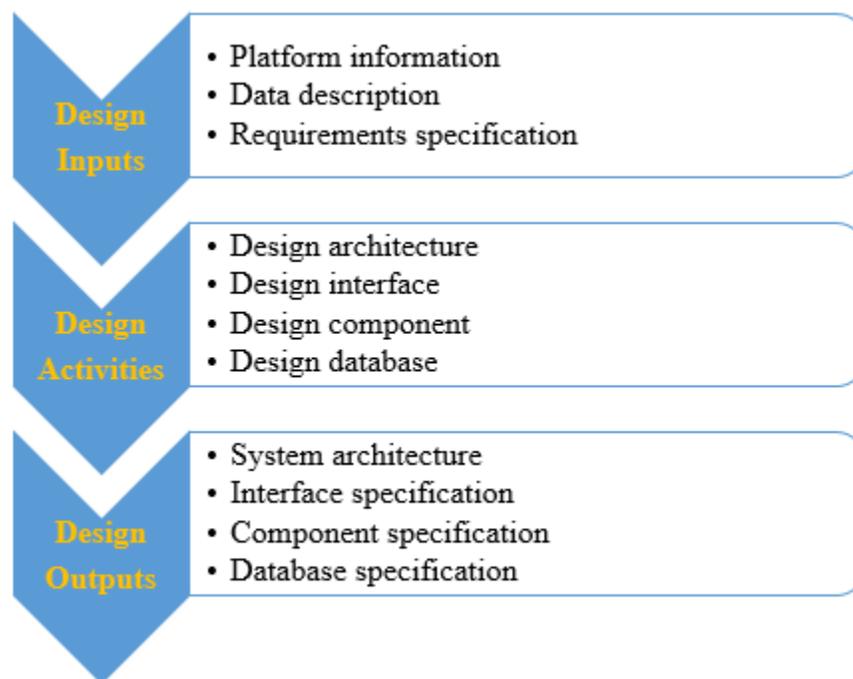
Figure 2. A general model of software system design process (adapted from Sommerville, I. (2009). Software engineering. Boston: Pearson/Addison-Wesley)

According to the above model, the design inputs typically include platform information, data description and requirements specification. The platform information indicates the

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environment in which the software executes. In this study, the knowledge assessment system was designed to run in the Linux environment. The data description is used for the system data organization, and it may belong with the platform information if the system is for processing existing data. The requirements specification consists of a depiction of the necessary functionalities and a description of the system performance and dependability requirements (Sommerville, 2009).

Four design activities are displayed in the above figure: (a) architectural design, which is for identifying the overall structure of the system, the major components, their relationships and how they are distributed; (b) interface design, which is for defining the interfaces between system components; (c) component design, which is for designing each component and describing how it operates; and (d) database design, which is for designing the data structures and their relationships within the system, as well as how these data are represented in the database (Sommerville, 2009; Pressman, 2010).

The four design activities lead to several design outputs, which are also displayed in Figure 2. The representations of the design outputs vary substantially. For example, for key systems, the detailed design documents should include the accurate descriptions of operational mechanisms. If using a model-driven approach, the outputs can mainly be diagrams (Sommerville, 2009). In this study, the design outputs were mostly diagrams with appropriate descriptions.

The next section focuses on these major parts: system requirements specification, architecture design, component design, interface design, and database design.

System Requirements Specification

The system requirements are the depictions focusing on what the system must do, which

reflect the needs of users. Requirements are classified into two main categories: functional requirements and non-functional requirements. Functional requirements are the requirements for desired functions of the system, and non-functional requirements are the quality properties of the system (Wieringa, 2014). Based on the literature review, the necessary features and functions for a knowledge assessment system based on concept maps were identified (see Table 5), but how the different necessary features are operationalized in the system requirements and how the necessary functions interact with user roles needed to be analyzed and ascertained.

Use cases are efficient for deriving system requirements from user roles of a system. A use case is a group of user's behavioral scenarios when using a system, and each scenario is depicted from an actor's perspective. An actor can be a user, device or component (Armour & Miller, 2000). Figure 3 shows the overview of use case diagram associated with this study's knowledge assessment system. This diagram illustrates how the three types of user roles interact with the system. To be specific, in this knowledge assessment system, an instructor user has three different types of scenarios: (a) creating a concept map task; (b) assigning a concept map task to the students; and (c) managing the assessment criteria and the knowledge assessment report. For the student users in this system, there are two different scenarios: (a) a student undertakes a concept map task, which might be resuming a task which was not completed at some earlier time or starting a new task; and (b) a student views a concept map task assessment report, downloading or exporting the report. For the administrator user, the different scenarios include: (a) managing student users and instructor users; (b) managing different concept map tasks; (c) managing different concept map task assessments; (d) managing task assessment reports; and (e) managing the configuration of the system. More use cases that describe the detailed interaction between the users and the system can be found in Appendix A.
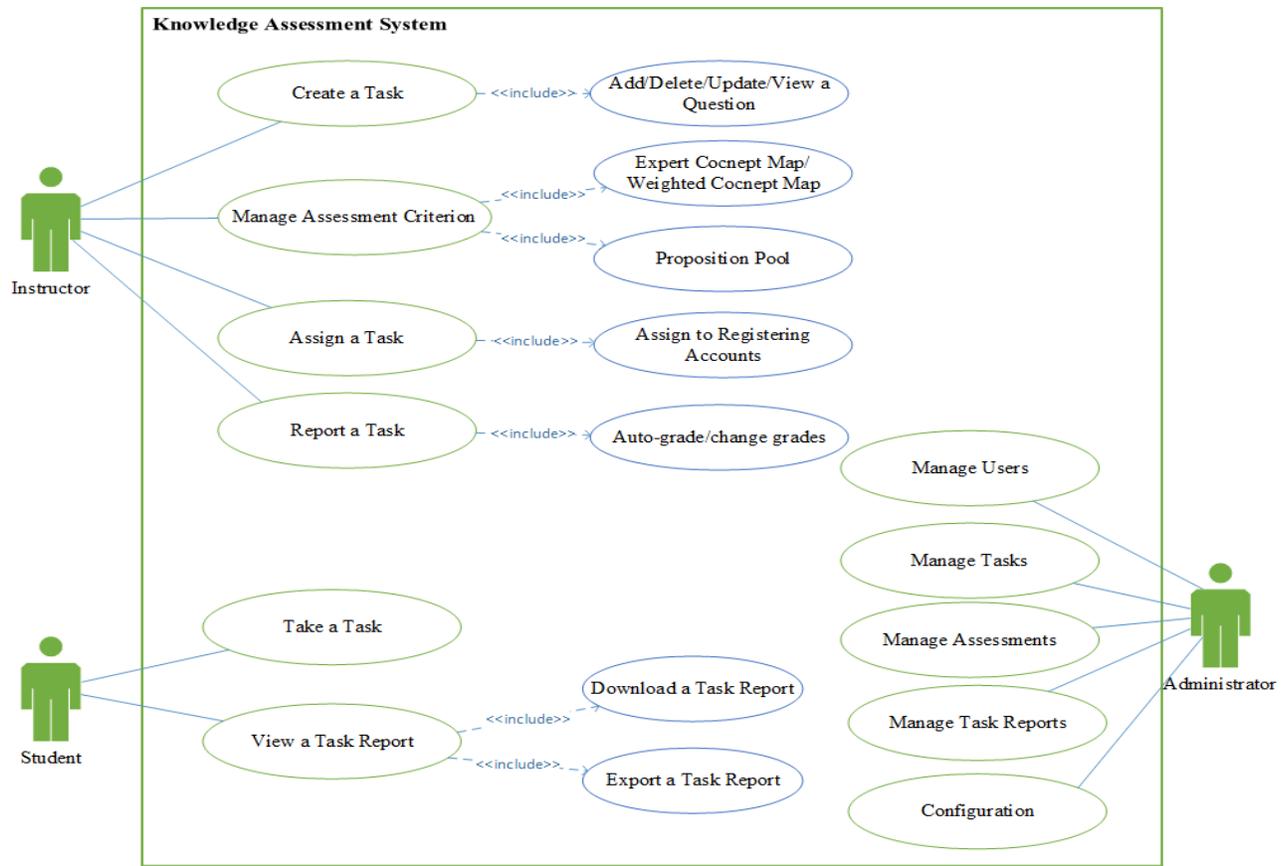
Figure 3. A use case for the knowledge assessment system

The functional requirements for the knowledge assessment system that were based on the results of the literature review and the system requirements analysis are shown in Table 9.

Table 9. *The Knowledge Assessment System Functional Requirements*

Category of system requirements	Descriptions
User Administration	Create, update, delete and view user profiles. User authentication and authorization. User importing and exporting.
Task Creation and Management	Create, update, delete and view different types of concept map tasks. Reuse the concept map tasks that are created earlier.
Task Assignment	Assign concept map tasks to students. Set beginning date and due date for the tasks.

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Task Taken	Resume an uncompleted concept map task.
	Start a new concept map task.
Student Response collection	Analyze student's responses to concept map tasks.
	Determine and store responses in propositional pools.
Evaluation and Feedback	Create, update, delete and view expert concept maps that act as assessment criteria.
	Create, update, delete and view weighted values of propositions.
	Update and improve the assessment criterion pool.
	Auto-assess student's concept map.
	Provide feedback.
Knowledge Assessment Report	Report the assessment result of student's performance on different types of knowledge.
	Deliver a knowledge assessment report.
	Download or export a knowledge assessment report.

Besides the above functional requirements of the knowledge assessment system, there were also some non-functional requirements associated with this knowledge assessment system. While the functional requirements focus on what the system must do, the non-functional requirements specify quality attributes such as reliability, security, usability and performance of a system (Robertson & Robertson, 2012). The non-functional requirements for this knowledge assessment system are displayed in Table 10.

Table 10. *The Knowledge Assessment System Non-Functional Requirements*

System Non-Functional Requirements Descriptions
The system shall be usable with Microsoft Internet Explorer browser version 6.0 or higher, Google Chrome version 38 or higher, Safari version 8 or higher and Mozilla Firefox version 32 or higher.
The system shall identify all of its users before allowing them to use its capabilities.
The system shall not be specific to an educational institution and anybody shall be able to create and administer a concept map task as well as use it.
The system shall provide well-formed graphical user interfaces.

The system shall enable the concept map tasks to be reusable by different assignments or tests.
The system shall ensure the user's personal information cannot be shared with any other users or a third party.
The system shall keep all database content and user settings unchanged after updating a patch.
The system shall ensure all data in the system can be exported in XML format.
The system shall enable all operations to be recorded in its log and support daily backup.

Architecture Design

The architectural design focuses on the representation of the functional system modules (sometimes called sub-systems or principal components by different scholars), their properties and interactions, and the overall functional structure of the knowledge assessment system.

A module is a single and predefined operating environment through which the system coordinates data flow and resource use. Dividing a software system into subsystems can provide better reusable resources, better-managed software development and easier maintenance (Sommerville, 2009; Pressman, 2010).

The architecture design for this knowledge assessment system included three steps: (a) identifying the principal system modules, (b) describing the interactions between these modules, and (c) designing the overall system structure.

Step1: Identifying the principal system modules. Through modularizing and decomposing this knowledge assessment system with the principle of maximizing cohesion within each module and minimizing dependencies between modules (Sommerville, 2009), five system modules were designed for this system: user module, concept map task module, assessment module, report module and administration module (see Figure 4). Each module is described in the following section.
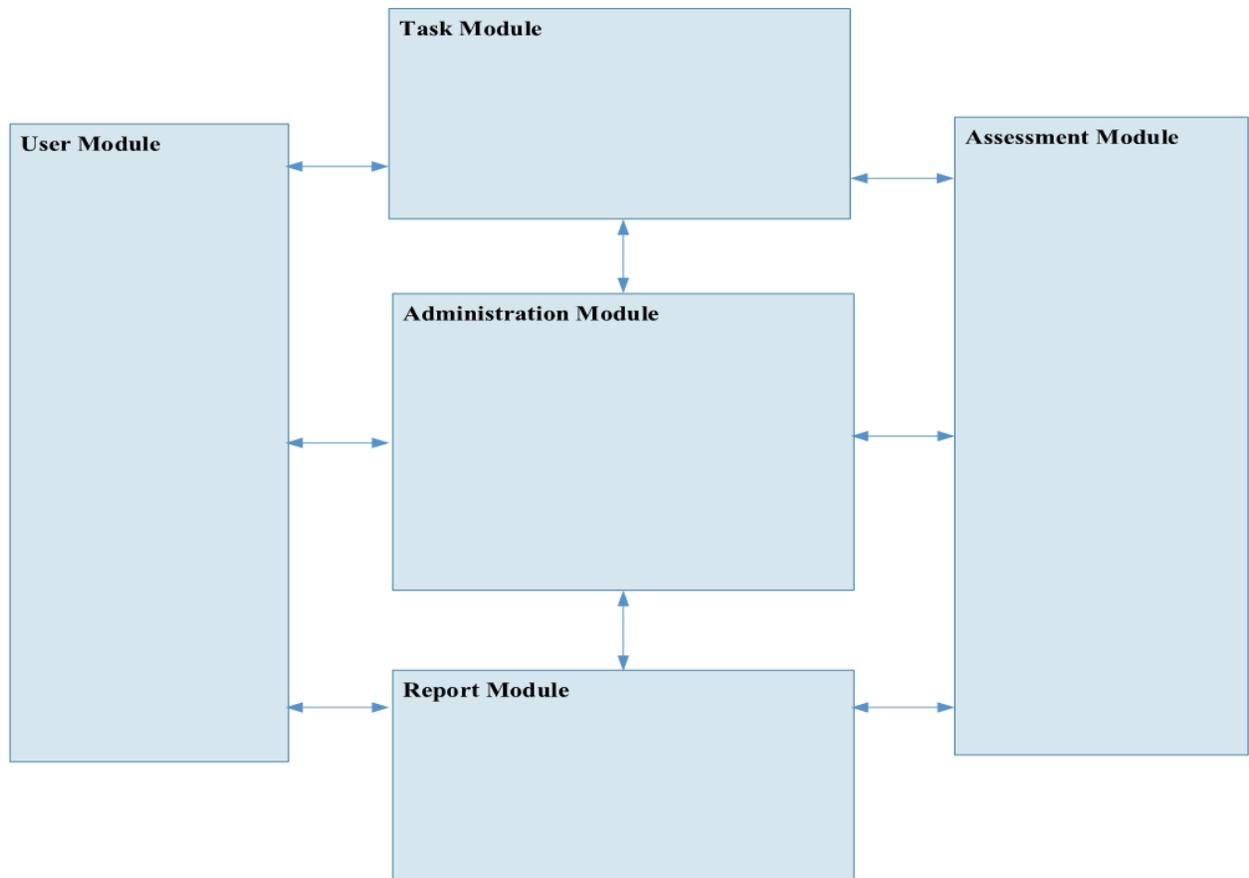
Figure 4. The five modules of the knowledge assessment system

The user module is responsible for user administration and user authentication. The
functionalities included in this module are user registration, user authentication, user authorization,
user management, and user password reset. With this user module, a student, instructor or
administrator can log into the knowledge assessment system, perform their respective roles and use
the corresponding functionalities.

The task module provides the functionalities related to a concept map task. These
functionalities include: creating a concept map task, adding or updating different concept map
questions in the task, maintaining the concept map task, assigning the concept map task and
undertaking the concept map task. With the task module, an instructor can create a concept map

task and assign the task to the students; a student can perform the task with a web browser connected to the Internet.

The assessment module is responsible for assessing the student-created concept maps and providing feedback. The functionalities included in this module are setting expert concept maps, setting weighted values for the propositions of the expert concept maps, maintaining proposition pools and auto-assessing the student-created concept maps.

The assessment report module provides the functionalities needed to report on students' knowledge based on their concept maps. With this module, the reports on students' knowledge can be automatically generated; an instructor can check or edit the reports, publish the reports or email the reports to the students; a student can also log into the system to view, download or export the reports from the system.

The administration module is in charge of all the management functionalities related to users, tasks, task assessments, knowledge assessment reports and system configurations. With this module, an administrator can manage instructor user accounts and student user accounts, administer concept map tasks, assessments and reports, as well as configure the system.

Step2: Describing the interactions between modules. The interactions between the different modules are displayed with sequence diagrams, which present graphical views of different scenarios that indicate the interactions in a time-based sequence (OMG, 2011). The following sections depict the interactions between the modules in this systems.

The interaction for creating a concept map task. In this system, an instructor may interact with the user module and task module to create a concept map task. After registering an instructor account in the knowledge assessment system, the instructor logs into the system and

obtains the authentication by the user module; then the instructor can create a concept map task

within the task module. Figure 5 shows how an instructor creates a concept map task.
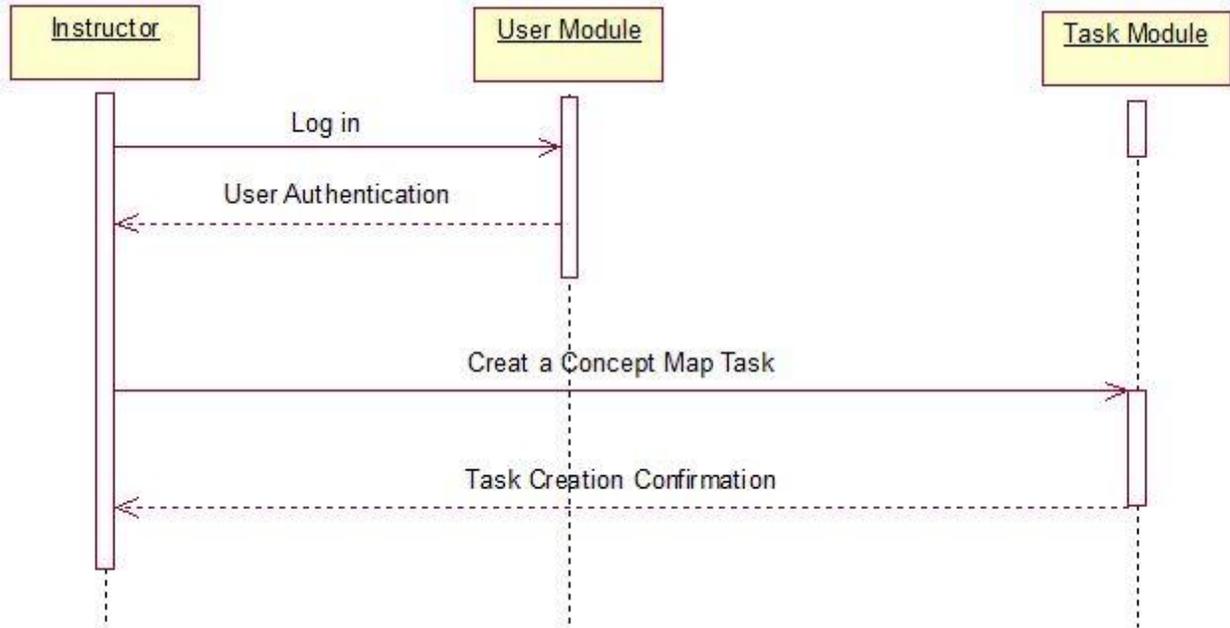
Figure 5. The interaction diagram of concept map task creation

The interaction for assigning a concept map task. In this system, an instructor may

interact with the user module and task module to assign a concept map task to students. After

getting a valid instructor account in the knowledge assessment system, the instructor logs in the

system and is authenticated by the user module, then the instructor can select one or more

student accounts from the user module, and assign a concept map task to these student accounts.

Figure 6 displays how an instructor assigns a concept map task to the students.
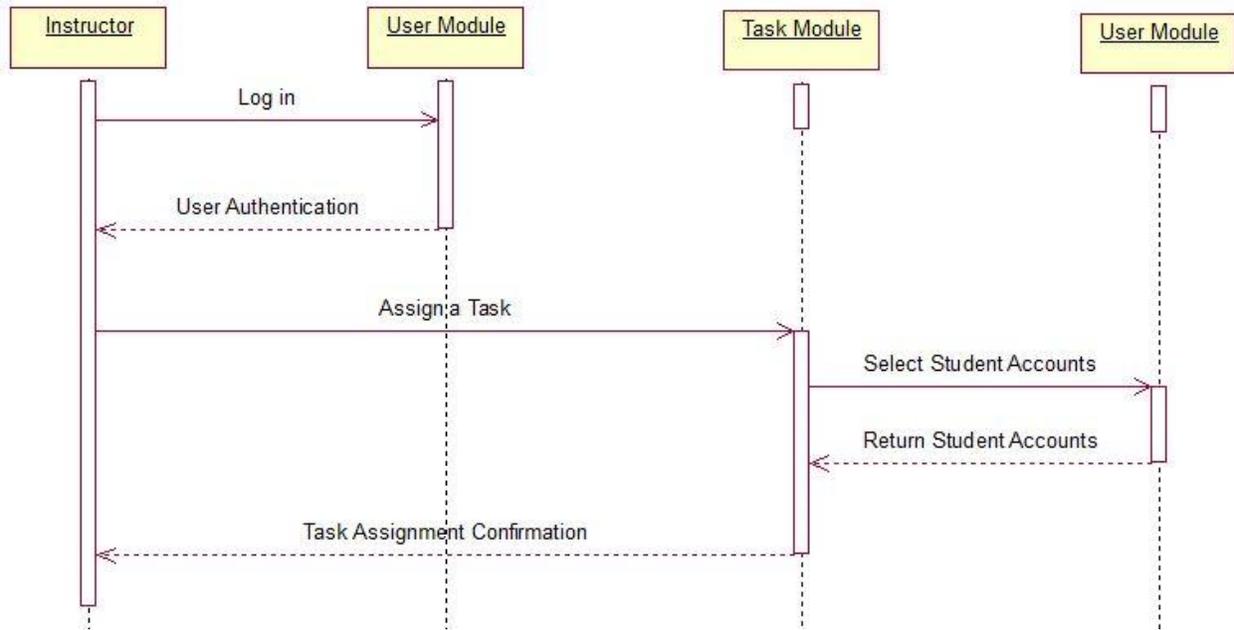
Figure 6. The interaction diagram of concept map task assignment

Other detailed interactions between modules can be found in Appendix B.

Step3: Describing the overall functional system structure. The overall functional system structure is designed on the basis of the defined modules and the interactions between these modules. The design of the overall system structure (see Figure 7) for this study indicates it is a three-tier Client-Server architecture. The knowledge assessment system includes five modules: user module, concept map task module, assessment module, report module and administration module. These modules are mainly situated in the application tier, which consists of a web server and a business logic server. The database server is located at the database tier, and the client tier allows three types of users (instructor, student and administrator) to connect the system with the web browser. Figure 7 shows the overall system function structure.
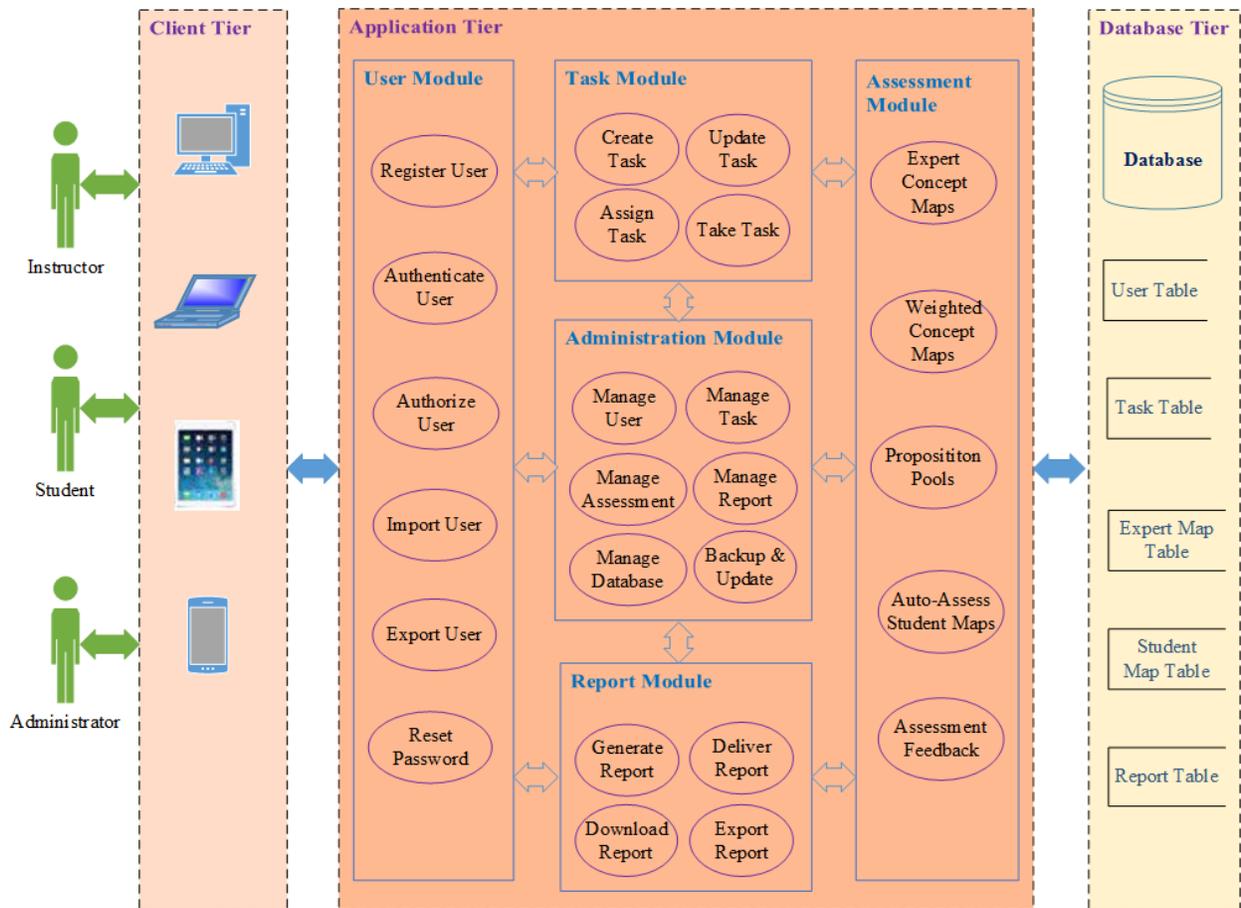
Figure 7. The overall functional system structure

Interface Design

The interface design described here refers to the internal interface design and does not include the user interface design; it focuses on designating the details of the interface to a list of objects in a module (an object refers to a variable, a data structure, a function or a combination of the three in the field of Computer Science) (Sommerville, 2009). In addition, from an object-oriented perspective, an interface is a set of operations that describes parts of the behavior of a class and provides access to these operations (a class refers to a template definition of the methods and variables in a particular kind of object; an object is an instance of a class in the field of Computer Science) (Pressman, 2010).

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For this knowledge assessment system, five internal interfaces were designed: user interface, task interface, assessment interface, report interface, and administration interface. These interfaces can be used to communicate with the different modules or components without knowing how they were implemented during the development process.

Component Design

The term component has diverse meanings depending on the perspective of the application developer who uses it. Traditionally, a component can be seen as a functional element of a program integrating processing logic, internal data structures, and an interface. In this sense, a component is similar to a module. But according to an objected-oriented view in the field of Computer Science, a component can contain a set of collaborating classes that encompass the attributes and functional operations (Pressman, 2010). In this research, a component was viewed as a type of module, and here the component design focused on the detailed functionality design for the five identified modules.

Detailed design of user module. The user module is responsible for user-related communication and management. There are three types of users in the knowledge assessment system: instructor, student and administrator. The instructor user and student user need to register with the system via the user module and obtain authentication when logging in; the administrator user is predefined but also needs to be authenticated when logging into the system. The detailed functionalities in the user module included: user registration, user authentication, user authorization, user password reset, user profile maintenance, user importing and user exporting (see Figure 8).
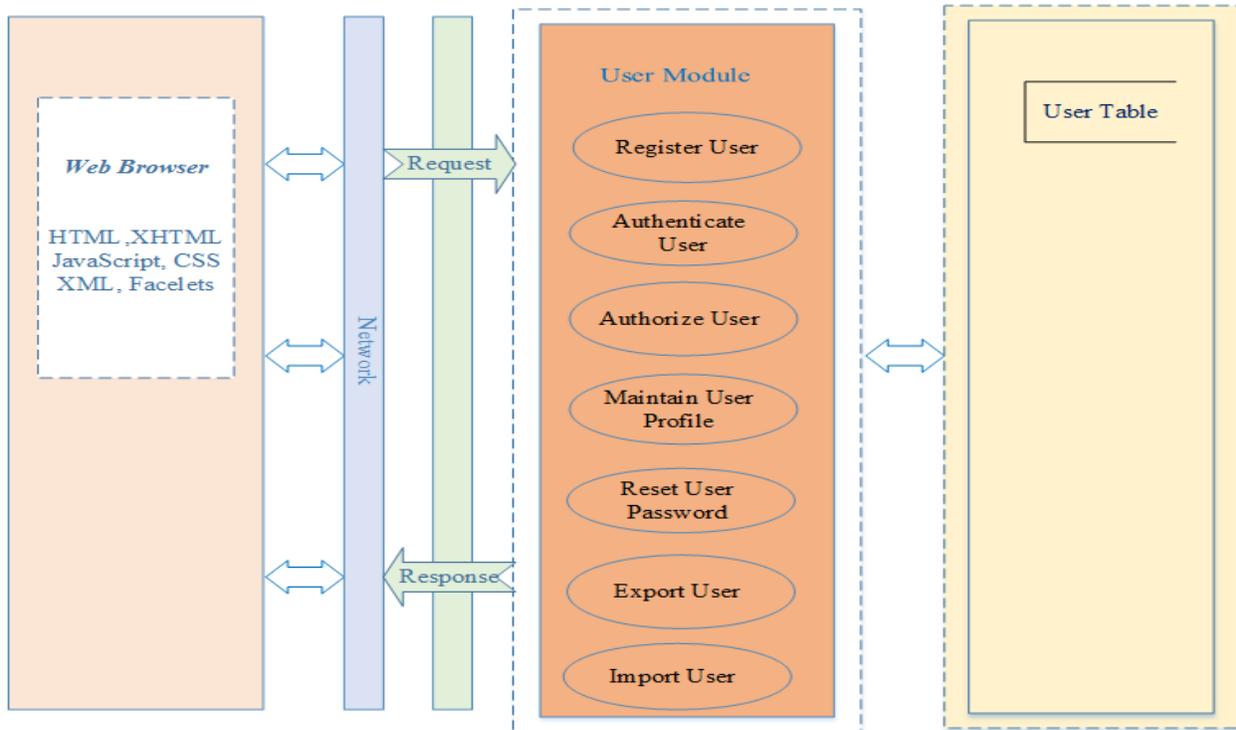
Figure 8. The detailed design of user module

All valid users can log into the system with a web browser. The following table indicates

the detailed functionalities of the user module (see Table 11).

Table 11. *The Description of the Detailed Functionalities of User Module*

Function	Description
Register User	The instructor user and student user can sign up for the system with a valid username and set the password. The administrator user is predefined, but the password can be changed after the administrator user logs in. An existing username cannot be registered again.
Authenticate User	All of the three types of users need to use a valid user name and password to log into the system. A non-existent or invalid username and password cannot be authenticated. If a valid username is used to log into the system more than three times within 5 minutes but fails due to a wrong password, the username will be suspended and cannot be authenticated in the subsequent 24 hours.
Authorize User	An instructor user can be authorized by an administrator user to have the privilege to do unrelated tasks like canceling his or her suspended

	student accounts and resetting passwords for his or her student accounts.
Maintain User Profile	All three types of users can maintain their user profiles, which includes updating personal information and setting which personal information may be published or not.
Reset User Password	All three types of users can choose to reset their passwords or ask an administrator to help reset.
Export User	An instructor user can choose to export the basic information of his or her student accounts, or an administrator user can choose to export the basic information of all user accounts. All privacy information cannot be exported. An exported template is provided.
Import User	An instructor can import a large amount of student account information to his or her online course; and an administrator can import a large amount of instructor account and student account information to the system. An imported template can be imported.

Other detailed component designs can be found in Appendix C. The detailed functionalities of each module within the component design are shown in the following figure (see Figure 9).

Knowledge Assessment System

User Module | **Task Module** | **Task Assessment Module** | **Task Report Module** | **Administration Module**

User Module:
- Register User
- Authenticate User
- Authorize User
- Create User
- Delete User
- Update User
- View User
- Reset User Password
- Export User
- Import User

Task Module:
- Create Task
- Update Task
- Delete Task
- View Task
- Add a Question to a Task
- Delete a Question from a Task
- Update a Question in a Task
- View a Question in a Task
- Assign Task
- Take Task
- Collect Task Response

Task Assessment Module:
- Create Expert Map
- Update Expert Map
- Delete Expert Map
- View Expert Map
- Add Weights for an Expert Map
- Delete Weights in an Expert Map
- Update Weights for an Expert Map
- View Weights in an Expert Map
- Add/Delete Proposition Pool
- Update/View Proposition Pool
- Auto-Assess Student Concept Map
- Set Assessment Feedback

Task Report Module:
- Generate Report on Student's Knowledge
- Check/ Edit Report on Student's Knowledge
- Publish Report on Student's Knowledge
- Email Report on Student's Knowledge
- View Report on Student's Knowledge
- Download Report on Student's Knowledge
- Export Report on Student's Knowledge

Administration Module:
- Manage User
- Monitor Task
- Manage Assessment
- Manage Report
- Manage Database
- Set Question Type
- Set Task Policy
- Set Instant Feedback
- Backup Data
- Software Update
- API

Figure 9. The detailed system functionalities of five modules

Database Design

The database design focused on designing the system data structures and describing how they are represented in a database. To be specific, it included identifying the information needed to be stored, determining the logical data structure, ascertaining data entities and attributes, designing the database tables and their data fields, and identifying the connections between these

database tables. For the knowledge assessment system, the open source database software –

MySQL was used. The following database tables were designed: user table, concept map question

table, concept map task table, student concept map table, assessment table, report table and

configuration table. Each database table has its data fields, and these tables can be connected with

a foreign key, depending on their relationships. The following diagram is an example for showing

parts of the tables and their relationships (see Figure 10).
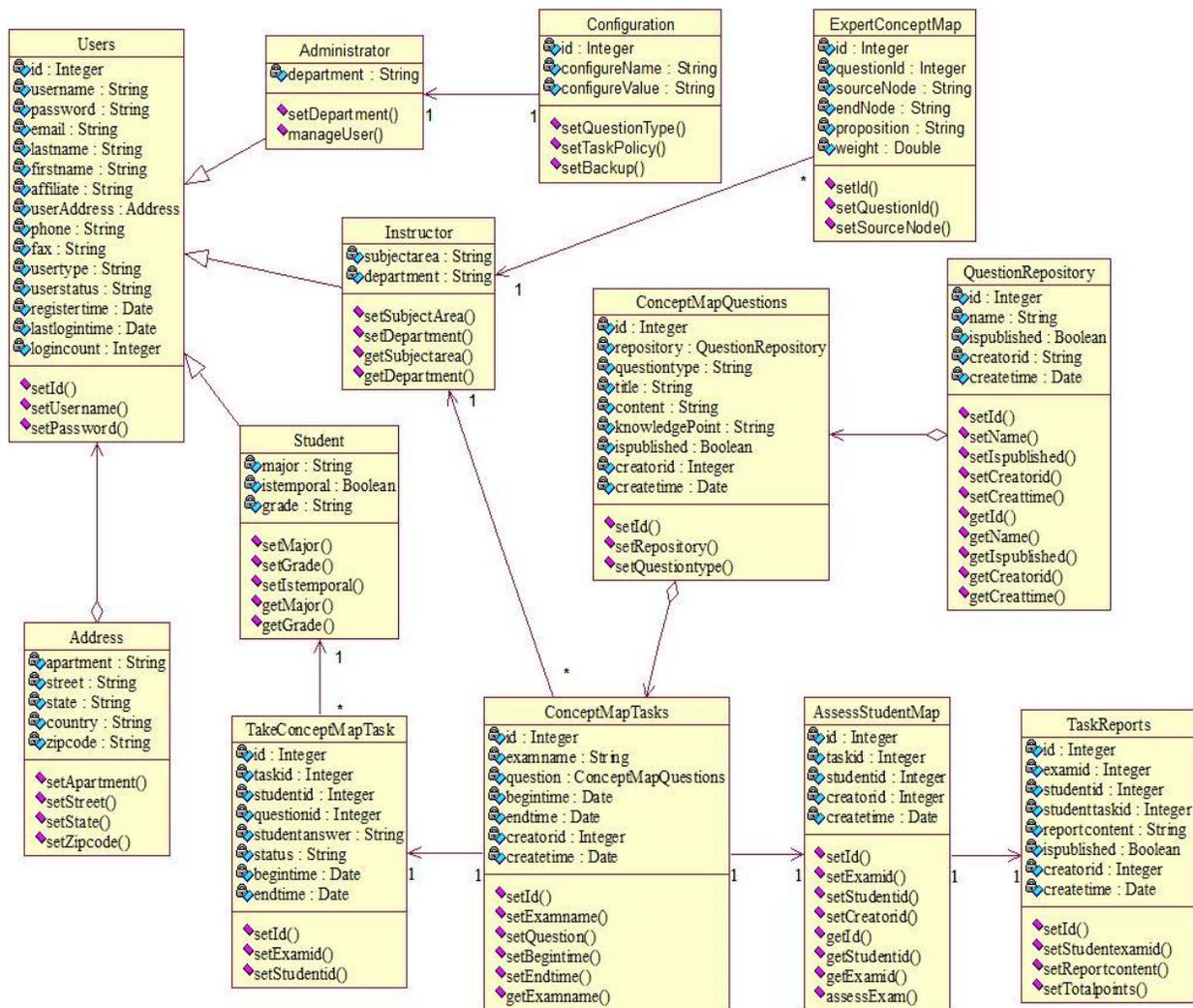
Figure 10. The class diagram of database design

The Development of Knowledge Assessment System Based on Concept Maps

The system was developed with these software or open source libraries: Glassfish4.1,

Netbeans8.1, Java8.0, MySQL5.6, JQuery1.9 and JQuery UI. It runs on the Linux platform.

The system development process included the following phases: (a) database

development, (b) user interface development, (c) system functionality development, and

(d) system test, improvement and deployment. Since the assessment algorithm and the

assessment report algorithm are important parts for the system functionality development, they

are also presented in this section.

The Development of Database

The database development for the knowledge assessment system involved multiple steps

that led to implementation of the designed database tables in the MySQL database. The steps

included: creating a database name in MySQL, creating the database tables, adding the data

fields into these database tables, and populating predefined data in some tables. For instance, an

administrator user name like "admin" was predefined in the user table; an example of a concept

map question also was predefined in the concept map question table. After that, it was necessary

to create a JDBC connection pool for performance purposes; the connection pool maintained

several database connections for reuse purposes.

The Development of User Interface

Three major interfaces were designed for the three types of users (instructor, student and

administrator) in the knowledge assessment system.

The instructor interface. The instructor interface includes a series of web pages

developed with HTML5, CSS3 and JQuery1.9. These interfaces consist of a concept map task

creation interface, an expert concept map assigned weights interface, a concept map task

assignment interface, an assessment criterion proposition management interface, and a

knowledge assessment report interface. The following is an example of an instructor interface

(see Figure 11).

Figure 11. The concept map task creation interface

The student interface. The student interfaces include: taking a concept map task interface,

creating student concept map interface and viewing knowledge assessment report interface.

Among the student interfaces, the creating student concept map interface allows for difficulty

levels ranging from simple to complicated, depending on the type of concept map task assigned

to the student. Four types of concept map questions may be presented in the creating student

concept map interface: fill-in-a-concept-map with provided node terms, fill-in-a-concept-map

with provided linking phrases, construct-a-concept-map with a partially pre-drawn map

provided, and construct-a-concept-map with nothing provided. The following is an example of a

student interface (see Figure 12).

Task Name: Personal Health Concepts		
Question Title	**Question Type**	**Action**
Please complete the fill-in-concept map based on the nodes	1-Fill-in-a-concept-map, providing nodes	Done / Edit
Please complete the fill-in-concept map based on the Linking Phases	2-Fill-in-a-concept-map, providing relationship	Done / Edit
Please complete the pre-drawn concept map tasks based on the material.	3-Construct-a-concept-map, providing partial one	Done / Edit
Please construct a concept map based on the material.	4-Construct-a-concept-map, providing nothing	Done / Edit

Figure 12. The creating student concept map interface

The administrator interface. The administrator interface is a dashboard which includes

several menus hyperlinking to sub web pages. These menus include: user administration, task

management, assessment management, report management, and system configuration.

Assessment Algorithm Development

The non-weighting approach and weighting approach are used together in the knowledge

assessment system. The non-weighting approach focuses on comparing the student concept maps

with expert concept maps in terms of the correctness and completeness of the propositions; the

weighting approach concentrates on comparing the student concept maps with expert ones in

term of weights of the propositions.

In the knowledge assessment system, each concept map is converted into a JSON file at

the back end, which is a data format. An example is shown as follows for converting a concept

map into a JSON file (see Figure 13 and Figure 14).
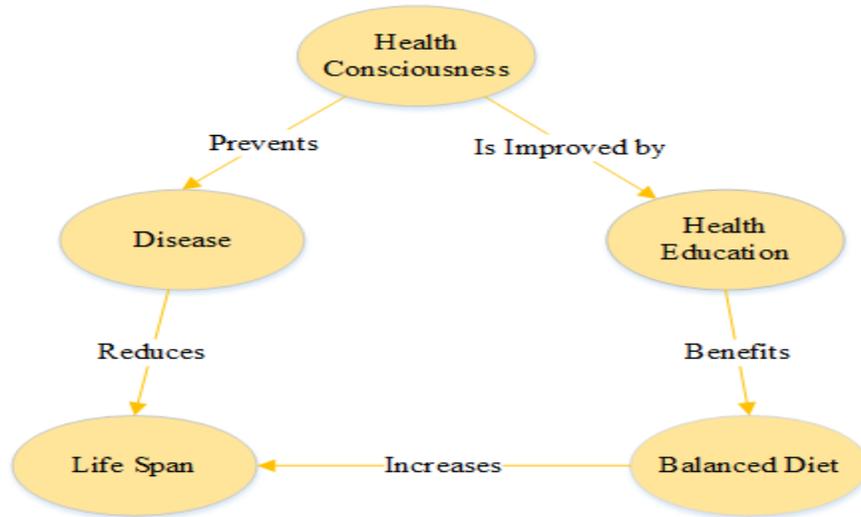
Figure 13. An example of concept map

Figure 14. An example of JSON file for a concept map

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According to the above JSON file, each node is assigned a unique number with coordinate values, and each proposition is described as two unique numbers with a linking phrase.

For an expert concept map, each node or linking phrase can be assigned weights, depending on the expert's configuration of scale-weights. The following table (see Table 12) displays an example for the propositions of an expert concept map with assigned weights, which are employed as the preliminary criterion for evaluating the student-created concept maps.

Table 12. *Propositions with Assigned Weights Coming from an Expert Map*

Source Node (Weights)	Relationship (Weights)	Target Node (Weights)	Category
Health Consciousness (2)	Prevents (3)	Disease (1)	Correct
Disease (1)	Reduces (2)	Life Span (1)	Correct
Health Consciousness (2)	Is Improved by (3)	Health Education (2)	Correct
Health Education (2)	Benefits (2)	Balanced Diet (2)	Correct
Balanced Diet (2)	Increases (3)	Life Span (1)	Correct

Note. Figures in parentheses denote the weighted values

For assessing a student's response to the fill-in-concept-map with provided nodes or linking phrases question, it is easy to compare the correctness and completeness of the propositions coming from a student's concept map with the expert's through the unique numbers mapping respective propositions, because the students cannot change the concept map structure and the unique numbers in student concept maps are the same as the numbers in expert ones. If the same number in a student map and an expert one respectively map a different node, then the student's answer is incorrect; otherwise the student's answer is correct. In addition, in the expert concept map, each node or linking phase may be assigned a weighted value, depending on the instructor's configuration. The results can be compared to provide a knowledge assessment report with listing of correct and incorrect propositions, as well as the corresponding weighted

values and the related statistical information, thereby demonstrating to what extent the student

has grasped the type of knowledge that the propositions convey.

If assessing a student's response to the construct-a-concept-map when provided a

partially pre-drawn map or nothing question, the system can compare the student's concept map

with the expert's based on proposition-by-proposition, which is adapted from Liu's (2010)

research efforts. In this situation, some propositions in student concept maps may be correct, but

the expert concept map may not contain them. In such cases, the assessment criteria need to be

refined and improved on the basis of the student-created concept maps. If a fill-in-a-concept-map

with provided partial or no node terms and linking phrases is assigned to a student, some of the

student-created propositions may also not be included in the expert map. The assessment criteria

then also need to be improved, and the assessment process for that kind of question is similar to

assessing a construct-a-concept-map question.

The following section shows how to assess a student's response to the construct-a-

concept-map question.
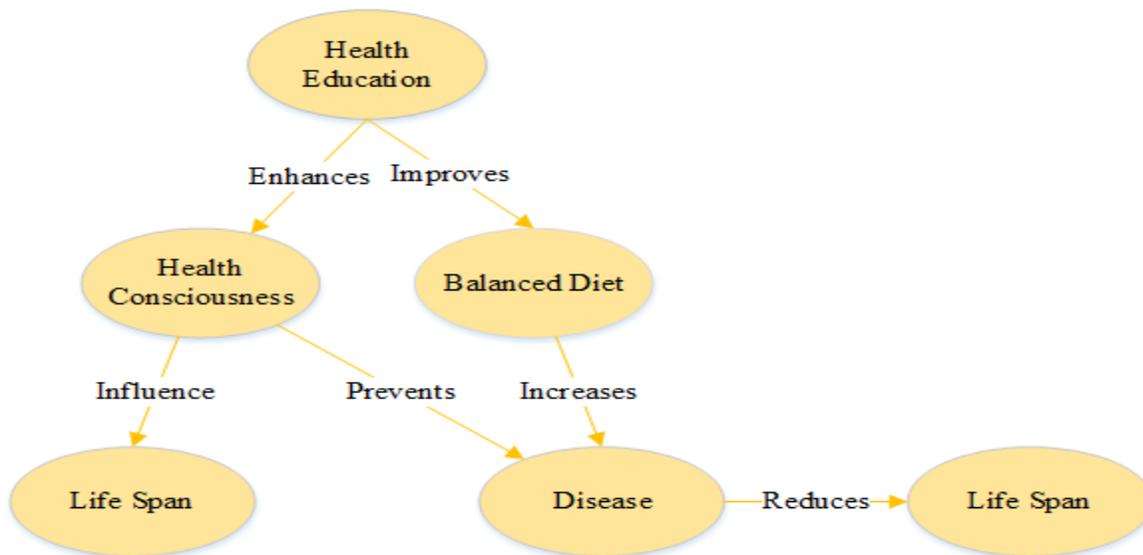
Figure 15. A student-created concept map

Table 13. *Propositions coming from a Student-created Map*

Source Node	Relationship	Target Node
Health Education	Enhances	Health Consciousness
Health Education	Improves	Balanced Diet
Health Consciousness	Influences	Life Span
Balanced Diet	Increases	Disease
Health Consciousness	Prevents	Disease
Disease	Reduces	Life Span

If a student's concept map is submitted (see Figure 15), it will be converted into a JSON file and then will be generated as a list of propositions (see Table 13). The system compares the list of propositions coming from the student's map with the list of propositions derived from the expert's map (see Table 12). The initial compared result is shown in Table 14.

Table 14. *Evaluation Outcome of a Student-created Map*

Source Node	Relationship	Target Node	Assessment Result
Health Education (2)	Enhances	Health Consciousness (2)	Different
Health Education (2)	Improves	Balanced Diet (2)	Different
Health Consciousness (2)	Influences	Life Span (1)	Different
Balanced Diet (2)	Increases (3)	Disease (1)	Different
Health Consciousness (2)	Prevents (3)	Disease (1)	Correct
Disease (1)	Reduces (2)	Life Span (1)	Correct
Health Consciousness (2)	Is Improved by (3)	Health Education (2)	Missing
Health Education (2)	Benefits (2)	Balanced Diet (2)	Missing
Balanced Diet (2)	Increases (3)	Life Span (1)	Missing

Note. Figures in parentheses denote the weighted values

According to the above table (see Table 14), the preliminary assessment results of the propositions coming from the student-created concept map are divided into three types: different, correct and missing. "Different" means that the proposition coming from the student-created map

does not exist in the expert map; "missing" indicates that the student has failed to include the proposition which exists in the expert map; "correct" means that the proposition exists in both the expert map and the student map. All of the corresponding weighted values are also shown in the parentheses located in the table.

The expert needs to review the propositions labeled as "Different" and identify whether they are correct or incorrect, as well as assign the appropriate weights to them if the weighting approach is used. After an expert finishes assessing these propositions, they will be added into a proposition pool, stored in the database, and used for future assessments. In this way, the proposition pool and the expert map will act as the refined evaluation criterion (see Table 15) for assessing the student's concept maps. Table 16 shows the final evaluation outcome for the student-created concept map. Since the proposition pool has identified the incorrect proposition, the initial evaluation results of other students' concept maps may include four types: different, correct, incorrect, and missing.

Table 15. *Refined Evaluation Criterion*

Source Node	Relationship	Target Node	Assessment Result
Health Education (2)	Enhances (2)	Health Consciousness (2)	Correct
Health Education (2)	Improves (2)	Balanced Diet (2)	Correct
Health Consciousness (2)	Influences (2)	Life Span (1)	Correct
Balanced Diet (2)	Increases (3)	Disease (1)	Incorrect
Health Consciousness (2)	Prevents (3)	Disease (1)	Correct
Disease (1)	Reduces (2)	Life Span (1)	Correct
Health Consciousness (2)	Is Improved by (3)	Health Education (2)	Correct
Health Education (2)	Benefits (2)	Balanced Diet (2)	Correct
Balanced Diet (2)	Increases (3)	Life Span (1)	Correct

Note. Figures in parentheses denote the weighted values

Table 16. *The Final Evaluation Outcome of the Student-created Concept Map*

Source Node	Relationship	Target Node	Assessment Result
Health Education (2)	Enhances (2)	Health Consciousness (2)	Correct
Health Education (2)	Improves (2)	Balanced Diet (2)	Correct
Health Consciousness (2)	Influences (2)	Life Span (1)	Correct
Balanced Diet (2)	Increases (3)	Disease (1)	Incorrect
Health Consciousness (2)	Prevents (3)	Disease (1)	Correct
Disease (1)	Impact (2)	Life Span (1)	Correct
Health Consciousness (2)	Is Improved by (3)	Health Education (2)	Missing
Health Education (2)	Benefits (2)	Balanced Diet (2)	Missing
Balanced Diet (2)	Increases (3)	Life Span (1)	Missing

Note. Figures in parentheses denote the weighted values

Knowledge Assessment Report Algorithm Development

The knowledge assessment report is generated on the basis of the assessment results of the student-created concept maps. To make it straightforward, three different types of concept map tasks are designed to assess three different types of knowledge – factual, conceptual and procedural knowledge.

The task of fill-in-concept-map with provided nodes or linking phrases is used to assess a student's factual knowledge or conceptual knowledge. The task of construct-a-concept-map with a provided pre-drawn one is employed to evaluate a student's procedural knowledge. Each type of concept map task could be used to assess more than one type of knowledge, and this depends on how the concept map tasks are designed. Since each node or linking phrase can be assigned weights, the knowledge assessment report should include the aspect of weights.

The factual knowledge assessment report and the conceptual knowledge assessment report based on the fill-in-concept-map tasks are similar (See Table 17 and Table 18). Table 19 shows an example of a procedural knowledge assessment report based on a construct-a-map task.

Table 17. *Factual Knowledge Assessment Report Based on the Fill-in-concept-map Task*

Student's Proposition	Expert's Proposition	Assessment Result
Arizona-Is abbreviated as-AZ	Arizona-Is abbreviated as-AZ (6)	Correct
Texas-Capital city is-Austin	Texas-Capital city is-Austin (7)	Correct
Michigan-Capital city is-Detroit	Michigan-Capital city is-Lansing (7)	Incorrect
Number of Correct Responses: 2	Number of Incorrect Responses : 1	
Weights of Correct Responses: 13	Weights of Incorrect Responses: 7	
Percent of Correct Weights: 13/20 = 65%	Percent of Incorrect Weights: 7/20 = 35%	

Note. Figures in parentheses denote the weighted values

Table 18. *Conceptual Knowledge Assessment Report Based on the Fill-in-concept-map Task*

Student's Proposition	Expert's Proposition	Assessment Result
Health Education- Improves- Health Consciousness	Health Education - Improves - Health Consciousness (6)	Correct
Health Education-Enhances- Balanced Diet	Health Education - Enhances - Balanced Diet (6)	Correct
Smoking -Increases - Life Span	Smoking - Decrease - Life Span (5)	Incorrect
Number of Correct Responses: 2	Number of Incorrect Responses : 1	
Weights of Correct Responses: 12	Weights of Incorrect Responses: 5	
Percent of Correct Weights: 12/17 = 70.59%	Percent of Incorrect Weights: 5/17 = 29.41%	

Note. Figures in parentheses denote the weighted values

Table 19. *Procedural Knowledge Assessment Report Based on the Construct-a-map Task*

Source Node	Relationship	Target Node	Weights	Assessment Result
Health Education	Improves	Balanced Diet	6	Correct
Health Consciousness	Influences	Life Span	5	Correct
Balanced Diet	Increases	Disease	6	Incorrect
Balanced Diet	Increases	Life Span	6	Missing

Number of Correct Responses: 2   Number of Incorrect Responses: 1

Weights of Correct Responses: 11   Weights of Incorrect Responses: 6

Percent of Correct Weights: 11/23 = 47.8%   Percent of Incorrect Weights: 6/23 = 26.1%

Number of Missing Responses: 1   Weights of Missing Responses: 6

Percent of Missing Weights: 6/23 = 26.1%

I designed, developed and deployed the system on a CentOS server situated in the Department of Computer Science at Virginia Tech. The system was tested on these web browsers: Google Chrome, Firefox, Internet Explorer, and Safari.

Formative Evaluation of the Knowledge Assessment System

After the initial version of the knowledge assessment system was developed and deployed, a formative evaluation consisting of two one-to-one evaluations and a pilot test was conducted to improve the system. One-to-one evaluation enables a researcher to obtain direct feedback from a participant to help improve an instructional system design (Dick, Carey, & Carey, 2009; Tessmer, 1993). A pilot test is frequently used to pre-test or try out a small-scale version of a research project and can help a researcher catch potential problems and prevent them from arising before full implementation occurs (Baker, 1994; Dodd & Williamson, 2004).

Two individuals participated in the one-to-one evaluation, and five college students with different backgrounds participated in the pilot test. The evaluation results were employed to refine and improve the user interfaces and system functionalities, as well as the related online materials used in the evaluations.

First One-to-One Evaluation

  Participant and materials. The first participant was a college student at Virginia Tech who was majoring in mathematics. He used an Apple MacBook Pro with OS X 10.9, Safari 7.0, and screen resolution of 1440 by 900. The materials consisted of the student directions for exploring the knowledge assessment system and the learning materials (see Appendix D and Appendix F). These materials were online and the participant could access them through the Internet.

  Procedure. During this evaluation process, only this participant and the researcher were involved. The researcher first briefed the participant on the research project. Second, the participant was informed of the purpose of the evaluation and provided the address of the evaluation website. Third, the participant was told to follow the online steps to complete the evaluation. The online steps included: reading the online consent form, learning the materials about the basics of concept maps and how to operate a concept map using the tool, downloading the student directions, following the directions to complete a concept map task consisting of three concept mapping activities, requesting an assessment report, and completing an online survey.

  The researcher observed the whole process when the participant agreed to allow such an observation. In addition, after the participant completed the online survey, the researcher asked the participant some questions, including: (a) were the learning materials easy to understand;

(b) were the concept map tasks appropriate for testing the system functionality; (c) did you have any comments or suggestions about the learning materials and the online survey; and (d) did you have any comments or suggestions for this system? It took about 1 hour and 10 minutes to complete the one-to-one evaluation.

Data collection. The data came from two sources: one was based on the participant's comments and suggestions as well as the researcher's observation, the other was based on the participant's responses to the online survey (see Appendix H), which consisted of 29 items and were grouped into these sections: participant's background, participant's computer configuration, user interface and system functionality, as well as the comments and suggestions for this tool. The online evaluation questions were adapted from Liu's research efforts (2010).

Results. On the whole, the participant was able to use the tool based on the step-by-step directions. The online materials were easy to understand and the system worked well. Yet, the evaluation still exposed some issues with the knowledge assessment system, and the participant offered some comments and suggestions for improving the tool.

Problems and suggestions related to the online materials and the system.

- There was a typo in the online material; the "serve" should be "survey".

- There were too many words about the introduction of operating concept maps using the tool; there was also a lack of figures for displaying the detailed introduction.

- Cannot delete a node or linking phrase for the construct-a-concept-map task, although it worked well when using a computer with Windows operating system.

- The font size was a little small in the interface of answering a construct-a-concept-map question.

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- Suggested providing more space for editing a concept map in the interface of answering a construct-a-concept-map question.

- Suggested providing simple instructions for operating a concept map in the interface of creating a concept map.

Revision. After the first one-to-one evaluation, the online materials and the tool were revised and improved based on the evaluation results. The revisions included:

- Fixing the typo in the online materials.

- Simplifying the introduction of operating concept maps and adding figures for demonstrations.

- Revising the *Delete* function and making it work on both a Mac computer and a Windows computer.

- Tweaking the font size for the interface of answering a construct-a-concept-map question.

- Providing a little more space for editing a concept map in the interface of answering a construct-a-concept-map question.

- Adding simple instructions for operating a concept maps in the interface of constructing a concept map.

After the revision, this tool was thoroughly tested again by the researcher and prepared for the second one-to-one evaluation.

Second One-to-One Evaluation

  Participant and materials. The second participant was a college student from the School of Education at Virginia Tech. She used a laptop with Windows 8.1, Google Chrome, and screen resolution of 1360 by 768. The revised materials consisted of the student directions for exploring the knowledge assessment system and the learning materials (see Appendix D and Appendix F). These materials were online and the participant could access them through the Internet.

  Procedure. During this evaluation process, only this participant and the researcher were involved. The researcher first briefed the participant on the research project. Second, the participant was informed of the purpose of the evaluation and provided the address of the evaluation website. Third, the participant was told to follow the online steps to complete the evaluation. The online steps included: reading the online consent form, learning the materials about the basics of concept maps and how to operate a concept map using the tool, downloading the student directions, following the directions to complete a concept map task consisting of three concept mapping activities, requesting an assessment report, and completing an online survey.

  The researcher observed the whole process when the participant agreed to allow such an observation. In addition, after the participant completed the online survey, the researcher asked the participant some questions, including: (a) were the learning materials easy to understand; (b) were the concept map tasks appropriate for testing the system functionality; (c) did you have any comments or suggestions about the learning materials and the online survey; and (d) did you have any comments or suggestions for this system? It took about 1 hour to complete the one-to-one evaluation.

Data collection. The data came from two sources: one was based on the participant's comments and suggestions as well as the researcher's observation, the other was based on the participant's responses to the online survey (see Appendix H), which consisted of 29 items that were grouped into these sections: participant's background, participant's computer configuration, user interface and system functionality, as well as the comments and suggestions for this tool. The online survey questions were adapted from Liu's research efforts (2010).

Results. In general, the tool functioned well, the online materials were easy to understand and the instructions were easy to follow. The participant said it was very straightforward and she had fun doing the evaluation. Yet, the evaluation still exposed some issues of the knowledge assessment system and the participant offered some comments and suggestions for improving the tool.

Problems and suggestions related to the online materials and the system

- There was a misspelled word in the online learning material; the "appearr" should be "appear".

- The item 18 in the online survey was not clear and it repeated the item 17 a little bit.

- Suggested making the concept map question related to procedural knowledge a little easier, since she had no idea of changing a flat tire for answering this question.

- Suggested using different background color to highlight the different types of assessment results in the knowledge assessment report.

- Suggested adding simple and concise explanations for the different assessment results in the knowledge assessment report,

- Suggested providing the drag-and-drop function for the fill-in-concept-map activity, rather than copying and re-inputting the node terms or linking phrase terms.

Revision. After the second one-to-one evaluation, the online materials and the step-by-step directions were refined; the online survey was revised; the user interface was improved based on the improvement of the tool. The revisions included as follows:

- Correcting the misspelled word.

- Changing the item 18 in the online survey to be totally different from the other items.

- Highlighting the different types of assessment results with different background colors in the knowledge assessment report webpage.

- Adding a simple and concise explanation for the different assessment results in the knowledge assessment report.

After the revision, this tool was systematically tested again by the researcher and prepared for the subsequent pilot test.

Pilot Test

Baker (1994) noted that the purpose of a pilot test is to help a researcher catch potential problems and prevent them from arising before full implementation occurred; the sample size of a pilot test was often a 10-20% of the sample size of an actual study (Baker, 1994; Dodd & Williamson, 2004). The pilot test for this research project involved five participants with diverse backgrounds — two from the School of Education, two from the Computer Science Department and one from the Department of Statistics. The major tasks for the participants included: learning the online materials, registering with the system, logging into the system, completing three concept mapping activities, requesting an assessment report, and completing an online survey.

Participants and materials. Five college students with different backgrounds participated in the pilot test. The materials consisted of the student directions for exploring the

knowledge assessment system and the learning materials (see Appendix D and Appendix F).

These materials were online and the participants could access them through the web browser.

Procedure. Before the pilot study, the participants received an email from the researcher that noted the purpose of the research project, the major tasks of the testing activities, and the web address of the tool website. The participants were informed that the pilot test would last for about 1 hour and that they needed to follow the online steps to complete the test. The online steps included: reading the online consent form, learning the materials about the basic knowledge of concept map and how to operate a concept map using the tool, downloading the student directions, following the directions to complete three concept map activities, requesting the knowledge assessment report, and completing an online survey.

Data collection. The data were based on the participants' responses to the online survey (see Appendix H), which consisted of 29 items and were grouped into these sections: participant's background, participant's computer configuration, user interface, system functionality, and the comments and suggestions for this tool. The online survey questions were adapted from Liu's research efforts (2010).

Results. I tried to find meaningful information from the data collected based on the participants' responses in the survey. The purpose of the pilot test was to evaluate the system functionalities, user interfaces and the learning materials to find the possibilities of improvements in the tool and to make sure that the tool could be ready for full-scale implementation.

Overall, the learning materials were easy to understand, and the system functions worked well. The participants were able to employ the system to complete the concept map activities though the step-by-step directions.

Some participants said the user interfaces were intuitive and friendly, and the concept map questions were interesting. However, the pilot test exposed some issues of the system, and the participants offered some suggestions to refine and improve the system functionality and user interfaces as well as the learning materials. The revealed issues and the suggestions are summarized in Table 20.

Table 20. *Feedback of the Pilot Test for the Knowledge Assessment System*

Category	Feedback
Learning Material	The instruction of operating concept map with this tool was written only for a user using a mouse with a scroll wheel, and it did not recommend a user to use a computer with a mouse.
Functionality	Did not support more than 10-character usernames and passwords when a user signed up. If registering a user name which existed in this system, the system could give proper hints, but the information input for other items like "First Name" would be deleted. Upon attempting to log in, the warning information "Invalid User" appeared. "Save Successfully" appeared after saving the concept map, suggesting changing it to "Saved Successfully". Preferred to see the instant assessment result for each concept map activity, instead of having to wait until completing all three concept map activities before seeing any results.
User Interface	Preferred to see a pop-up window instead of opening a new tab window when creating a concept map. Suggested changing the term "Begin" on the button to the term "Take", change the term "Answer" into "Complete" in the interface of taking a concept map task. The interface of creating a concept map overlapped slightly when browsing it through Safari on an iPad. The interface of listing concept map questions was a little crowded when there were more than 10 records.

Revisions. After the pilot test, the knowledge assessment tool was revised on the basis of the results of the data analysis. Because the aim of the pilot test and the subsequent revisions

was to make the tool perform well when it was fully implemented, the participants' feedback on personal preferences was excluded. The revisions included the following:

- Adding content about recommending that the users use a mouse to operate a concept map in the online learning materials.

- Tweaking the function to support more than 10-character user names and passwords when a user signed up.

- Removing the warning message of "Invalid user name or password" when a user typed the password.

- Changing the message "Save Successfully" to "Saved Successfully" after a user saved a concept map.

- Tweaking the layout of the interface of creating a concept map to make it dynamically support the screens of different types of computers.

- Tweaking the layout of the interface of listing concept map questions to allow a user to scroll down in the interface, if there were more than 10 records.

After the revision, this tool was thoroughly tested again by the researcher and prepared for a summative evaluation consisting of a small-group evaluation and a subject-matter expert review.

Summative Evaluation of the Knowledge Assessment System

The summative evaluation included a small-group evaluation and a subject-matter expert review. The small-group evaluation involved more student participants for the evaluation of the improved system functionality and its user interfaces, so as to identify the student users' opinions and concerns and help improve the system. The subject-matter expert review included two

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experts for the evaluation of the improved system, with the aim of identifying the instructor

user's or expert users' opinions and concerns and refining the system.

Small-Group Evaluation

Participants and materials. The participants were recruited through email invitation.

Thirty-eight students at Virginia Tech responded that they were interested in participating in the

small group evaluation, but just 36 students registered with the system and completed the three

concept map activities, and 35 persons submitted the online evaluation survey.

The 35 participants who submitted the online survey consisted of 5 undergraduate

students and 30 graduate students. They had various educational backgrounds, including

education, engineering, science, technology, mathematics and social science. Sixteen participants

had experience using knowledge assessment tools, and 19 participants had experience evaluating

web-based tools. Twenty participants used a Windows computer and 15 persons employed an

Apple computer to complete the evaluation.

Materials used in the evaluation consisted of the learning materials and the student

directions for exploring the knowledge assessment system (see Appendix D and Appendix F).

These materials were online and the participants could access them through the Internet.

Procedure. Before the small group evaluation, the participants received an email from

the researcher that indicated the purpose of the research project, the major tasks of the evaluating

activities, and the web page link of the system. These participants were informed that the

evaluation would last about 1 hour and they could follow the online steps to complete the

evaluation. The online steps included: reading the online consent form, learning the materials

about the basics of concept maps and how to operate a concept map using the tool, downloading

the directions, following the directions to complete three concept map activities, requesting the knowledge assessment report, and completing an online evaluation survey.

Data collection. The data collection was based on the online evaluation survey (see Appendix H), which consisted of 29 items that were grouped into the following sections: participant's background, participant's computer configuration, user interface and system functionality, as well as the comments and suggestions for this system**.** The online survey questions were adapted from Liu's research efforts (2010).

The evaluation results of the small-group evaluation are presented in the next chapter.

Subject-Matter Expert Evaluation

Participants and materials. Two experts in the Instructional Design and Technology field participated in the subject-matter expert review. Both of the experts have expertise in instructional technology and knowledge assessment. They are full professors in different public research universities in U.S. and both of them have more than 20 years teaching and research experience in the Instructional Design and Technology field.

The review materials included seven mandatory short videos (about 15 minutes long in total) and four optional short videos (about 10 minutes long in total), which were based on the expert directions for evaluating the knowledge assessment system, the learning materials and three types of concept map activities within the system (see Appendix D, Appendix E and Appendix G). The purposes of these short videos were to help the experts know the system functionalities quickly and be able to use this system shortly, as well as assisting them in focusing on evaluating whether the system could be used to assess students' factual, conceptual and procedural knowledge based on the students' concept maps and two differential weighting approaches. The topics of these short videos included: (a) introduction of the evaluation package;

(b) general description of concept maps and their components; (c) demonstration of the system's functions; (d) demonstration of a factual knowledge assessment; (e) demonstration of a conceptual knowledge assessment; (f) demonstration of a procedural knowledge assessment; (g) demonstration of reports generated by the knowledge assessment system; (h) using the system as an instructor to create three assessments; (i) completing the concept mapping questions as a learner; (j) viewing the outcomes as an instructor; and (k) using the instructor tools to refine the assessments like scoring non-normal responses or weighting responses. These materials were online and the experts could access them through the Internet.

Procedure. Before the subject-matter expert evaluation, the experts received an email from the researcher, which indicated the purpose of the research project, the major tasks of the evaluating activities, and the web page link of the review package. The two experts were informed that the evaluation would last about half an hour and they could follow the online steps to complete the evaluation. The online steps included: viewing the seven necessary videos and four optional videos, trying out the system, and completing an online evaluation survey.

Data collection. The data collection was based on the online evaluation survey (see Appendix I), which included 18 items and was divided into the following sections: factual knowledge section, conceptual knowledge section and procedural knowledge section, as well as the comments and suggestions for this system.

The evaluation results of the subject-matter expert review are presented in the next chapter.

Chapter Four: Results

The purpose of the study was to design and develop a knowledge assessment system for assessing students' different types of knowledge, as defined in the revision of Bloom's Taxonomy (Anderson et al., 2001). Ideally, the system would be based on concept maps and would employ two differential weighting approaches.

Seven categories of functionality for the knowledge assessment system were identified on the basis of the results of the literature review and the system requirements analysis. These functionalities were user administration, task creation and management, task assignment, task taken, student response collection, evaluation and feedback, and knowledge assessment report. These functions were incorporated successfully into the knowledge assessment system and descriptions of their functionalities are shown in Table 21.

Table 21. *The Functions of the Knowledge Assessment System*

Category	Descriptions
User Administration	The system allows a valid user to create, update, delete and view the related user profiles. The system allows an administrator to manage the instructor user accounts and student user accounts. The system allows an administrator to export or import instructor accounts and student accounts with provided templates. The system allows an instructor to export or import his or her student user accounts with provided templates.
Task Creation and Management	The system allows a valid instructor to create, update, delete and view four types of concept mapping activities (e.g., fill-in-a-concept-map with provided node terms, fill-in-a-concept-map with provided linking phrases, construct-a-concept-map with a partial one provided, and construct-a-concept-map with nothing provided). The system allows an instructor to reuse the concept map tasks created earlier.

Task Assignment	The system allows an instructor to assign concept map tasks to a student. The system allows an instructor to set begin date and due date for a concept map task.
Task Taken	The system allows a valid student to resume an uncompleted concept map task. The system allows a valid student to start a new concept map task.
Student Response Collection	The system accepts a student-created concept map, converts the concept map into a JSON file, and inserts it into the database. Then the system informs that the student the concept map has been submitted successfully. The instructor checks the student's responses and decides the undetermined propositions coming from the student's map to be correct or incorrect (may assign a weight here), and adds them into the proposition pools.
Evaluation and Feedback	The system allows a valid instructor to create an expert concept map with the assigned weights for a map task. The system allows a valid instructor to create and improve the assessment criterion pools. The system auto-assesses the students' maps based on the assessment criteria and provides feedback.
Knowledge Assessment Report	The system generates a knowledge assessment report based on a student-created concept map. The system allows an instructor to review a knowledge assessment report and re-assess a student map, as well as deliver it through email. The system allows a student to download or export an assessment report.

The non-weighting approach and optional weighting approach also were incorporated successfully into the knowledge assessment system for both instructors and students. The interactive elements of this assessment tool provide learners with engaging ways to demonstrate various types of knowledge with concept mapping and the knowledge reports generated by the tool provide timely feedback to the learner and the instructor. The learner could use this feedback to measure learning progress and evaluate study strategies. The instructor could use the feedback

as a formative assessment tool to guide instruction or summative assessment tool to assess the learners' knowledge of the subject matter.

The knowledge assessment system based on concept maps and two differential weighting approaches was designed to allow users to access files or data resources via web browsers. The three-tier Client-Server architecture employed in this study is a distributed computing architecture and would be appropriate for a knowledge assessment system based on the results of the study's literature review. Five modules were designed in the knowledge assessment system: user module, task module, assessment module, report module, and administration module. These modules were mainly situated in the application tier of the three-tier Client-Server architecture and communicated with the client tier and database tier through the related Internet protocol. The operability of the five modules within the three-tier Client-Server architecture was investigated as part of a group evaluation and subject-matter expert reviews, the details of which will be presented later in this chapter.

The literature suggests that the revision of Blooms' Taxonomy (Anderson et al., 2001) provides a distinct knowledge concept for subdividing knowledge into four types: factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge. The first three types of knowledge were addressed in this knowledge assessment system. The knowledge definitions and terminologies defined in the revision of the taxonomy were used to help design different types of concept map tasks to assess students' corresponding knowledge, so as to give a clearer picture of what types of knowledge the students have mastered and to what extent they have grasped that knowledge after studying curriculum content.

The literature also suggested that it should be possible to auto-assess student concept maps with both a non-weighting approach and a weighting approach. The non-weighting

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approach includes counting the valid nodes and linking phrases in student-constructed concept maps, as well as comparing student-created concept maps with expert ones on a proposition-by-proposition basis in terms of correctness and completeness; the weighting approach means assigning different weights to different nodes or linking phrases in expert concept maps based on relevant factors, such as the degrees of importance, and comparing student-created concept maps with the expert ones on a proposition-by-proposition basis in terms of weights. The non-weighting approach can help assess what types of knowledge a student has mastered, and the weighting approach can help evaluate to what extent a student has grasped some type of knowledge that the propositions convey.

This study took the revision of Blooms' Taxonomy as a guide to design four types of concept map tasks – fill-in-a-concept-map with provided nodes, fill-in-a-concept-map with provided linking phrases, construct-a-concept-map with a partially pre-drawn map provided, and construct-a-concept-map with nothing provided, as well as integrating the weighting approach and non-weighting approach together to help assess different types of student knowledge.

Although the weighting approach and non-weighting approach both use the expert concept maps as preliminary criteria in this study, the expert concept maps may not cover all of the valid propositions and some propositions in student-created concept maps may be considered to be correct. Therefore, the effectiveness of using the expert concept maps as criteria depends on the ongoing accuracy and thoroughness of the expert concept maps.

The rest of this chapter provides the results of a summative evaluation of this system.

Results of Summative Evaluation

The summative evaluation includes a small-group evaluation and a subject-matter expert review. The small-group evaluation involves more student participants for the evaluation of the

improved system functionality and its user interfaces, so as to identify the student users' opinions and concerns and help improve the functionality of the system. The expert review includes two experts for the evaluation of the improved system, with the primary aim of determining if the system is capable of assessing factual, conceptual, and procedural knowledge, as well as identifying the instructor user's or expert user's opinions and concerns and refining the system.

Results of Small-Group Evaluation

The participants' responses to the online evaluation questions in the small-group evaluation were analyzed; the means and standard deviations of these responses are displayed in Table 22. The numbers denote responses on a Likert scale: 1 for strongly disagree, 2 for disagree, 3 for agree, 4 for strongly agree. The range of means is between 2.94 and 3.89. The evaluation results indicated that the participants in the small-group evaluation were generally satisfied with the Knowledge Assessment System with regard to user interface and system functionality.

Table 22. *Means and Standard Deviations of Participants' Responses in Small-Group Evaluation*

Evaluation Questions	M	SD
The information on each interface is easy to read.	3.63	0.60
The color arrangement on each interface helps provide a clear display.	3.74	0.56
The font size and style on each interface are appropriate.	3.54	0.61
It is easy to find the needed information on each interface.	3.66	0.59
The different information settings are clearly separated from one another.	3.77	0.55
The functions of buttons and menus work correctly.	3.60	0.65
The concept map task function is easy to follow.	3.37	0.65
The concept map questions are arranged in a good structure.	3.51	0.66
It is easy to add node terms or linking phrase terms in a fill-in-concept-map task.	3.26	0.61
It is easy to change node terms or linking phrase terms in a fill-in-map task.	3.31	0.63
For construct-a-concept-map task, it is easy to create nodes or linking phrases.	3.46	0.66

For construct-a-concept-map task, it is easy to remove node or linking phrases.	3.29	0.62
For construct-a-concept-map task, it is easy to change the directional linking line.	3.11	0.53
It is easy to rearrange and reorganize a concept map.	3.49	0.61
It is easy to zoom in or zoom out a concept map with mouse.	3.63	0.60
The knowledge assessment report is structured well and easy to understand.	2.94	0.64
The knowledge assessment report provides useful information about what kinds of knowledge I have grasped.	3.00	0.59
The icons are consistent among all of the interfaces.	3.66	0.59
The color arrangements are consistent among all of the interfaces.	3.77	0.55
The font size and style are consistent among all of the interfaces.	3.89	0.47
The text menus are consistent among all of the interfaces.	3.86	0.49
The layouts are consistent among all of the interfaces.	3.83	0.51
The same categories of information have consistent location on the interfaces.	3.80	0.53

Note. N=35. M-means, SD-standard deviation.

User interface. On average, 94.29% of the participants in the small-group evaluation rated "strongly agree" or "agree" for the items related to the user interface. Their suggestions pertaining to refining and improving the user interfaces concentrated on the editing construct-a-concept-map region, the skin of the interface and the color options. For example, the expert concept map for a procedural knowledge activity had 11 nodes. If students created more than 11 propositions in their concept maps, the editing region for constructing a concept map became somewhat crowded. Some participants suggested enlarging the concept map editing space, although they could zoom in or zoom out of the concept map in order to increase or decrease the available editing space. In addition, different participants had different preferences for the color of concept maps and the skin of web pages. For example, some participants suggested providing a function that allowed users to set different colors for different nodes, linking phrases or linking lines within a concept map; some participants suggested providing the interface templates with different styles and colors, so as to give the users more options.

System functionality. On average, 91.43% of the participants in the small-group evaluation rated "strongly agree" or "agree" for the items related to the system functions. All buttons and hyperlinks functioned well, and the operations of filling in a concept map and constructing a concept map were not hard. Some participants encountered a problem when they changed a linking line direction for a new node. Another issue mentioned by some participants was that the "different propositions" and "weights" in the knowledge assessment report were not easy to understand. Several participants alleged that some of those "different propositions" may be correct, and that the "weight" may be in a range which needed a detailed explanation.

Comments and suggestions. The participants' comments and suggestions were summarized as follows: (a) it was interesting to complete the concept mapping activities; (b) it was easy to complete the fill-in-a-concept-map activity, but it was not easy to drag a node and reorganize a concept map when answering a constructing-concept-map question; the editing space was a little crowded; (c) the instruction webpage opened in a different window from the actual web page of constructing-a-concept-map, which made it a little difficult to switch back and forth; (d) there was no process to assist a user who had forgotten his or her password; (e) there was no total score in the knowledge assessment report; (f) some participants preferred to use a tab window rather than a new pop-up window when answering concept map questions; (g) some participants preferred to set different colors for different nodes linking phrases and linking lines in a concept map; (h) some participants preferred to see the explanations of the assessment results at the top of the webpage containing the knowledge assessment report, rather than at the bottom of the webpage; and (i) some participants recommended providing a function for displaying the original student answer map in the webpage of knowledge assessment report.

Results of Subject-Matter Expert Evaluation

As can be seen in Table 23, both of the two experts rated "strongly agree" or "agree" for all of the items in the survey. They agreed that the Knowledge Assessment System could assess a student's factual, conceptual or procedural knowledge based on a comparison of the student's propositions with the propositions of an expert. They also agreed that the system could support the use of both a non-weighting approach and a weighting approach for assessing the student's factual, conceptual or procedural knowledge.

Table 23. *Subject-Matter Expert Evaluation Results*

Evaluation Questions	R1	R2
Given an appropriate question, the system can support a student's creation of a concept map responding to the question.	4	4
Given propositions contained in a student's concept map, the system can assess the student's *factual knowledge* based on a comparison of the student's propositions with the propositions of an expert.	4	4
The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *factual knowledge*.	4	4
The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in the expert map) for assessing student's *factual knowledge*.	4	4
The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *factual knowledge* based on the concept map question.	3	4
Given propositions contained in a student's concept map, the system can assess the student's *conceptual knowledge* based on a comparison of the student's propositions with the propositions of an expert.	4	3
The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *conceptual knowledge*.	4	3
The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in the expert map) for assessing student's *conceptual knowledge*.	4	3
The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *conceptual knowledge* based on the concept map question.	3	3

	R1	R2
Given propositions contained in a student's concept map, the system can assess the student's *procedural knowledge* based on a comparison of the student's propositions with the propositions of an expert.	3	3
The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *procedural knowledge*.	3	3
The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in expert map) for assessing student's *procedural knowledge*.	3	3
The Knowledge Report component of the system contains a function that can support an instructor's assessment of the undetermined propositions (the different propositions in the knowledge report for assessing student's *procedural knowledge*) coming from students' concept maps to be either correct or incorrect, as well as assign them weights for future assessment.	3	3
The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *procedural knowledge* based on the concept map question.	3	3

Note. R1 and R2 are reviewers. In scales, 1=strongly disagree, 2=disagree, 3=agree, 4=strongly agree.

System functionality and usability. Both of the two experts thought the system

functionality was generally satisfactory and the system was easy to use. The experts commented:

Each function was easy to use and effective from an instructional standpoint with regard

to demonstrating relationships among targeted facts to be learned. The demonstration of

the system allowed for manipulation and input for each function of the assessment and I

was able to generate my own assessment instrument with no problems. The report

generation feature created accurate and clear documentation of student responses. I found

this aspect of the program easy to use as well. (Expert I)

The directions of this system are clear. The system is easy for both instructors and

students to use, for example, the tasks can be set by the instructor based upon which type

of knowledge s/he would like to assess. From an interface design standpoint, students

should find the system intuitive and easy to use as well. The generation and manipulation of nodes and links is straightforward, permitting the effective communication of relationships among ideas (facts, concepts, or procedures). (Expert II)

Use for assessment of three types of student knowledge. For evaluating the effectiveness of the system for assessing students' factual, conceptual and procedural knowledge based on concept maps, one expert gave detailed encouraging comments and another expert offered generally positive comments:

The system easily allows instructors to create assessments, add weights, and generate reports of student performance related to their comprehension of factual knowledge. (Expert I)

As in the conceptual knowledge portion of the system, the conceptual knowledge concept mapping was easy to use from both the student and the instructor perspectives. In creating an assessment of conceptual knowledge, I was able to add, edit, and delete items with no trouble. The demonstration was effective in showing how to go about creating an assessment of conceptual knowledge as well. (Expert I)

For assessing student procedural knowledge, I found this section of the program to be particularly impressive, given the instructor's ability to review responses that do not align with the expert's responses, make adjustments to the score if the response is indeed correct, and then add that particular term or response to the repository of possible future responses. Thus, the system gets more robust with use. This kind of flexibility in scoring and system development based on input adds another level of value to this tool. (Expert I)

This system provides an innovative way to assess student factual, conceptual, and

procedural knowledge. (Expert II)

Overall comments of the experts. Both of the two experts gave very positive comments

about this system. For example, the experts commented:

Generally, the Knowledge Assessment System can help students use concept maps to

understand the attributes and relationship of the learning objectives and provide a visual

tool for them to work through the process of thinking, organizing thoughts, and viewing

the patterns. It has built-in assessment and reporting tools so instructors can easily assess

students' progress by evaluating progress reports. This system provides an innovative

way to assess student's factual, conceptual, and procedural knowledge. (Expert I)

The system easily allows instructors to create assessments, add weights, and generate

reports of student performance related to their factual, conceptual and procedural

knowledge. From an instructional design perspective, you have developed a largely

automated mechanism that supports the use of concept maps to measure learning in a

pedagogically sound manner. (Expert II)

Suggestions of the experts. The experts' suggestions for future development included

(a) improving the qualities of demonstration videos in terms of the low resolution and the

monotone voice of the narrator, (b) providing drag-and-drop function for users to build the

concept map for the fill-in-a-concept map task, and (c) offering a function for displaying the

original concept maps in the knowledge assessment report webpage.

Chapter Five: Discussion and Future Research

This chapter discusses how the overall design of this knowledge assessment system can provide a useful knowledge assessment report for both instructors and students, what and how this study contributes to the current literature, and what lessons the researcher has learned during the research project. Also, possible future developments and study and the limitations are discussed.

The Design of the Knowledge Assessment

Knowledge Types and Concept Map Tasks

Based on the literature review, the revision of Bloom's Taxonomy (Anderson et al., 2001) provides a distinct concept of knowledge that defines four types of knowledge in the cognitive domain. These four types of knowledge are factual knowledge, conceptual knowledge, procedural knowledge and metacognitive knowledge.

Among the four types of knowledge, factual knowledge and conceptual knowledge are similar, because they involve the knowledge of what. But conceptual knowledge is a deeper, more integrated and systematic knowledge than factual knowledge, which focuses on terminology and basic facts. Procedural knowledge consists of the knowledge of rules, algorithms, and procedures and involves the knowledge about how to do something. Metacognitive knowledge is the knowledge about general cognition and one's own cognition (Anderson et al., 2001). The first three types of knowledge were addressed in the system and the last one was not.

The types of knowledge that can be evaluated by the knowledge assessment system depend on what types of concept map tasks can be designed. In this study, these four types of concept map tasks were designed: fill-in-a-concept-map with provided nodes, fill-in-a-concept-

map with provided linking phrases, construct-a-concept-map with a partially pre-drawn map provided, and construct-a-concept-map with nothing provided.

The fill-in-a-concept-map with provided nodes task indicates that a pre-drawn concept map with blank nodes has been provided, and that students need to fill in the appropriate node blanks. An instructor can choose to provide all of the related node terms with distracters for the students to choose from, or just provide some node terms, or none at all. The fill-in-a-concept-map with provided linking phrases task means that that a pre-drawn concept map with blank linking phrases has been provided, and the students need to fill in the appropriate linking phrase blanks. An instructor can choose to provide all of the related linking phrases with distracters for the students to choose from, or just provide some linking phrases, or none at all. The construct-a-concept-map task with a partially pre-drawn map provided indicates that some elements of a concept map are completed and the students need to complete the blank elements based on their understanding of some domain-knowledge. The construct-a-concept-map with nothing provided task means that the students need to draw a concept map from scratch without any provided information after they study a chapter or a particular learning material. The four types of concept map tasks designed in this system contain the concept map tasks implemented in related research on assessment tools based upon concept maps (Chang et al., 2005; Gouli et al., 2005; Liu, 2010; Lukasenko & Anohina-Naumeca, 2010), but are more flexible and more holistic while operating within a single system.

In order to make the evaluation process straightforward, I focused on using three types of concept map tasks to respectively assess student's factual knowledge, conceptual knowledge and procedural knowledge in a particular domain in this study (see Appendix E), and left assessing student's metacognitive knowledge with concept mapping tasks for future research. The

evaluation results showed that these three types of concept map tasks could be used to assess the students' factual, conceptual and procedural knowledge. The findings that different concept map tasks can be used to assess specific types of knowledge are in agreement with the research results of scholars such as Ruiz-Primo (2004) and Williams (1998).

Concept Map Scoring Approaches

The scoring approaches in the knowledge assessment system were categorized as non-weighting approach and weighting approach (see Table 24). They were both based on comparing student-created concept maps with experts' maps. These two approaches had been separately or jointly used in different studies, and the results of evaluating their reliability and validity were positive (Herl et al., 1999; McClure et al., 1999; Ruiz-Primo et al., 2001; Rye & Rubba; 2002; Yin & Shavelson, 2008).

In this study, the knowledge assessment system was designed to support both of these two scoring approaches based on using expert concept maps as criteria, along with the four types of concept map tasks. Compared with a single scoring method used in previous research, combining these two methods together for different concept map task assessments in this knowledge assessment system provides an instructor with more options to score student-created concept maps appropriately, as well as a more comprehensive picture of what types of knowledge their students have grasped, and to what extent their students have mastered that knowledge.

Table 24. *Two Categories of Scoring Methods in the Knowledge Assessment System*

Scoring Approach	Description
Non-weighting Approach	Comparing a student's concept maps with an expert's map in terms of the correctness and completeness of propositions.
Weighting Approach	Comparing a student's concept maps with an expert's map in terms of the weights of propositions.

The scoring process was depicted as follows:

For the fill-in-a-concept-map task with provided nodes or linking phrases, it was relatively easy to auto-assess a student's concept maps through comparing the student's answers with an expert's answers on a proposition-by-proposition basis in the knowledge assessment system. Since the structures of the concept maps would be provided and could not be changed by the students, the students just needed to fill in the blanks of concept maps through selecting the appropriate node terms or linking phrases from the provided ones. This is similar to a multiple-choice question to some extent; it is not hard for a system to auto-assess such type of question.

The construct-a-concept-map task was a little more complicated, since the structure of the concept maps could be changed by the students. In this situation, the students could create any proposition in their concept maps in any structure; some student propositions may not be included in the expert map. In that case, the student propositions needed to be considered to see if they were correct. Therefore, the assessment criteria needed to be updated over time in order to reflect the addition of student propositions that have been deemed to be correct or incorrect.

If a fill-in-a-concept-map task with partial or nothing provided was assigned to the students, the scoring process was similar to assessing a construct-a-concept-map task. Since the student's propositions might not be included in the expert map but might be correct, the assessment criteria also needed to be updated over time.

The assessment process was adapted from Liu's research efforts (2010), which included two phases. First, an instructor needed to create an expert concept map with assigned weights or not as a criterion for a concept map task; after a student's concept map was submitted, the system would auto-assess the student's concept map by comparing it with the expert's initial concept map and provide a temporary assessment result. The temporary assessment was based on the

proposition-by-proposition comparison and the evaluation result included three possible outcomes: different, correct, or missing. The "different" designation indicated that the proposition came from student concept maps but did not appear in the expert maps; the "missing" designation meant that the student failed to include the proposition that appeared in the expert concept maps.

Second, the instructor inspected the "different" propositions. The instructor could identify the "different" propositions to be either correct or incorrect, as well as assign the weighted values to the propositions if the weighting approach would be used. Then the identified correct and incorrect propositions would be added to the evaluation criterion pool, and the evaluation criteria would be refined and improved and contain four types: different, correct, incorrect, and missing.

Subsequent student-created concept maps would be evaluated through comparing them with the refined and improved evaluation criteria. When more and more subsequent students' responses were scored, more incorrect or correct propositions coming from these students' concept maps would be added to the evaluation criteria pool, and given enough student maps, the evaluation criteria pool eventually could cover all possible propositions with weights (if assigned), which could help automatically provide more reasonable assessment results.

The summative evaluation results of the knowledge assessment system indicate that the two differential weighting approaches can work well together within this system to provide more options for instructors to score student-created concept maps appropriately. The findings that the two weighting approaches can be jointly used to assess student knowledge, to a large extent, support the research results of scholars such as Herl et al. (1999), McClure et al. (1999) and Rye and Rubba (2002).

Knowledge Assessment Report

The knowledge assessment report in the knowledge assessment system had two distinct

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formats, depending on the concept map tasks and scoring approaches. For a fill-in-a-concept-map task, when the non-weighting approach was employed, the knowledge assessment report would list a student's propositions and the corresponding expert propositions in the same row but in different columns of a table; the assessment result of each proposition, including two categories – correct or incorrect, would be displayed at another column in the same row of the proposition in the table. Other statistical information like the total number of correct propositions and its percentage would be shown at the bottom of the table. When the weighting approach was used, the weighted value for each proposition would be presented; the statistical information such as the sum of weights for correct propositions and its percentage would also be provided.

For a construct-a-concept-map task, when the non-weighting approach was employed, initially only the list of student's propositions and the corresponding assessment results were displayed in a table. The assessment result for each proposition would be presented; the automatic evaluation result of each proposition might be: correct, incorrect, different, or missing (Liu, 2010). Next, an instructor could re-assess each proposition marked as "different" and determine it to be correct or incorrect though clicking the "Assess" button. Finally, the updated statistical information like the total number of correct propositions and its percentage would be shown at the bottom of the table. When the weighting approach was used, the weighted value for each proposition was displayed; the statistical information such as the sum of weighted values for correct, incorrect, different or missing propositions and their percentages would also be provided. Each proposition labeled as "different" could be re-assessed and assigned a weighted value by an instructor. The detailed information about the knowledge assessment report in the system is presented in Table 25. The knowledge assessment report designed in this system includes the partial or total report content presented in related studies on assessment tools based

on concept maps (Chang et al., 2005; Grundspenkis, 2011; Liu, 2010), but is more flexible and more personalized while operating within a single system.

The evaluation results showed that the assessment report could provide very useful information to both students and instructors about what kinds of knowledge (factual, conceptual and procedural) and to what extent a student had mastered that knowledge that the propositions conveyed. Major suggestions from the student users included providing a function for displaying the original concept maps in the assessment report webpage, along with the list of propositions converted from the concept maps. One expert reviewer also suggested exhibiting the original expert maps in the report webpage. These suggestions will be considered in future research.

Table 25. *Assessment Report in the Knowledge Assessment System*

Concept Map Task	Scoring Approach	Knowledge Assessment Report Description
Fill-in-a-map (providing total, partial or no node terms or linking phrases)	Non-Weighting Approach	List student's propositions and corresponding expert's propositions in the same row of a table. Display assessment result for each proposition: correct or incorrect. Display the respective total number for correct and incorrect propositions. Display the respective percentage for correct and incorrect propositions.
	Weighting Approach	Display the weighted value of each proposition. Display the respective sum of weighted values for correct and incorrect propositions. Display the respective percentage of weighted values for correct and incorrect propositions.
Construct-a-map (providing a partially pre-drawn map or none)	Non-Weighting Approach	List student's propositions. Display assessment result for each proposition: correct, incorrect, different or missing. For the "different" proposition, an instructor can re-assess it to be correct or incorrect. Display the respective total number for correct incorrect, different or missing propositions. Display the respective percentage for correct, incorrect, different or missing propositions.
	Weighting Approach	Display the weighted value of each proposition. Display the respective sum of weighted values for correct incorrect, different or missing propositions.

	Display the respective percentage of weighted values for correct, incorrect, different or missing propositions.
	For the "different" proposition, an instructor can re-assess it and assign a weighted value.

Contributions of this Study

Investigating the feasibility and practicability of using concept mapping and two differential weighting approaches within a system for different types of knowledge assessment and the limitations of current assessment systems based on concept maps has been the motivating force for the researcher to conduct this study. The contributions of this study include several aspects as follows.

First, the developed knowledge assessment system based on concept maps incorporates the non-weighting approach and weighing approach together for knowledge assessment, which not only eliminates the assumption of equal degree of importance of any proposition when scoring a student concept map found in some existing computer-based tools based on concept maps such as SemNet (Fisher, 2000) and Assessment Agent Tool Based on Concept Maps (Liu, 2010), but also addresses the degree of inflexibility of scoring methods for using one assessment approach found in some existing tools such as Weighted Concept Map Tool (Chang et al., 2005) and Assessment Agent Tool Based on Concept Maps (Liu, 2010). Thus, this system provides more flexibility and more options for instructors to score student-created concept maps appropriately within a single tool.

Second, this knowledge assessment system based on concept maps was designed and developed to benefit both instructors and learners; it can automate the scoring process as well as generate timely knowledge assessment reports. The learner can use the immediate feedback to measure learning progress and evaluate study strategies. The instructor can use the feedback as a

formative assessment tool to guide instruction or as a summative assessment tool to assess the

learners' three types of knowledge in a subject domain. Therefore, this system can be used for

both formative and summative assessment purposes, rather than only for formative assessment as

in some earlier studies (Beaudry & Wilson, 2009; Conlon, 2006; Trumpower & Sarwar, 2010).

Third, this knowledge assessment system based on concept maps employs the knowledge

defined in the revision of Bloom's Taxonomy (Anderson et al., 2001) for assessment purposes;

this system is domain-independent and it expands the assessment of limited types of knowledge

or general knowledge based on concept maps found in some research (Cline et al., 2010; Gouli et

al., 2004; Grundspenkis, 2011).

Lessons Learned

The researcher chose the design and development approach (Richey & Klein, 2007) and

the general model of software system design process (Sommerville, 2009) to design and develop

the knowledge assessment system based on concept maps and two differential weighting

approaches. The study included three major phases: design phase, development phase and

evaluation phase.

Design Phase

In the design phase, the researcher used the findings from the literature review to identify

the necessary features for the knowledge assessment system based on concept maps and two

differential weighting approaches. Then followed the application of a general model of software

system design process (Sommerville, 2009) to clarify and analyze the system requirements with

use cases, select an appropriate architecture through comparing several widely used architecture

patterns, and design the system components, interface and database. The design phase took the

researcher more than three months to complete; the most challenging part was to elicit system requirements and ascertain the system components and detailed functionalities.

Development Phase

In the development phase, the researcher first built a web server and database server on a local computer for writing, testing and debugging the codes without network connection. After completing all of the development work, all of the source codes and the database files were migrated into a CentOS Server located in the Department of Computer Science at Virginia Tech. The migration was smooth, but the researcher detected that the database was not stable and sometimes did not work on the CentOS Server. This issue had never appeared on the researcher's computer. Later the researcher recognized that the Server was running Linux, which was totally different from Windows run on the researcher's computer. This issue was fixed by resetting a configuration variable on the CentOS Server.

Evaluation Phase

After the developed knowledge assessment system was deployed successfully on the CentOS Server, the researcher conducted a formative evaluation and a summative evaluation. The formative evaluation consisting of two one-to-one evaluations and a pilot test involving five participants with diverse backgrounds was used to test and revise the system in terms of its user interface and system functionality. The summative evaluation included a small-group evaluation contained 35 participants and a subject-matter expert review involving two experts in the Instructional Design and Technology field. The small-group evaluation focused on revealing the student user's perceptions about using the system. The subject-matter expert review concentrated on revealing instructor user's or expert user's perceptions on the usage of the system and evaluating the effect of the system for assessing factual, conceptual and procedural knowledge in

a subject domain. For recruiting the student participants, the researcher planned to use multiple listservs to involve as many student participants with different backgrounds as possible. Because the evaluations were conducted in the summer and a limited number of students registered during that time, almost all the student participants were recruited through email invitation. For recruiting the expert reviewers, the researcher wanted to seek the experts who had at least 10 years' experience related to knowledge assessment in the Instructional Design and Technology field. Three experts were identified and the researcher contacted with them via email invitation. Probably the evaluation schedule was a little tight and, as a result, two experts indicated their willingness to participate in this study and one did not reply.

The findings from the summative evaluation indicated that the non-weighing approach and weighting approach were able to be incorporated into the knowledge assessment system well; the system satisfied the student user and instructor user needs and could be a useful tool for assessing students' three types of knowledge (factual, conceptual and procedural) on the basis of their concept maps.

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Limitations and Future Study

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Limitations

This study included several limitations. First of all, not all of the desired functions were developed for the evaluation due to time and human resource limits. For example, the use of concept maps to auto-assess student's metacognitive knowledge was deliberately excluded from the evaluation phase. Second, this study employed a limited number of participants and reflected the overviews of only a portion of the population. In all likelihood, the opinions of some persons in the population may differ from those of the participants in this study. Additionally, for the small-group evaluation, 35 college students at Virginia Tech participated in the evaluation; these

participants may have similar prior experience or knowledge that might have affected the evaluation results.

Future Developments and Study

This study focused on the design and development of a knowledge assessment system based on concept maps and two differential weighting approaches. More development work is needed in some areas. For example, some functionalities of the system can be improved. The following are some possibilities for future development.

- Improve the student interface. Provide a means for the students to drag-and-drop the node terms or linking phrases to complete a fill-in-a-map task, as well as provide a method for the students to set color for the nodes, linking phrases and linking lines.

- Improve the functionality of managing assessment criteria by allowing the instructors to set flexible assessment criteria like partially correct propositions and negative weights.

- Improve the functionality of the knowledge assessment report by allowing the students or the instructors to click a button to see the student map and the expert map in the knowledge assessment report webpage, besides listing the propositions converted from the two concept maps in tables.

In addition to functional improvements, involving more experts to review the system and to investigate the large-scale effectiveness of the knowledge assessment system in assessing students' three types of knowledge (factual, conceptual and procedural) when learning curricular content could provide useful information.

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Appendix A: Use Cases

The following figure (see Figure A1) shows the concept-map-task-creation use case. An instructor can create a concept map task and name it, add a concept mapping question into the task, update the question in the task, delete the question from the task and view the question in the task, as well as change the attributes for the question in the task.
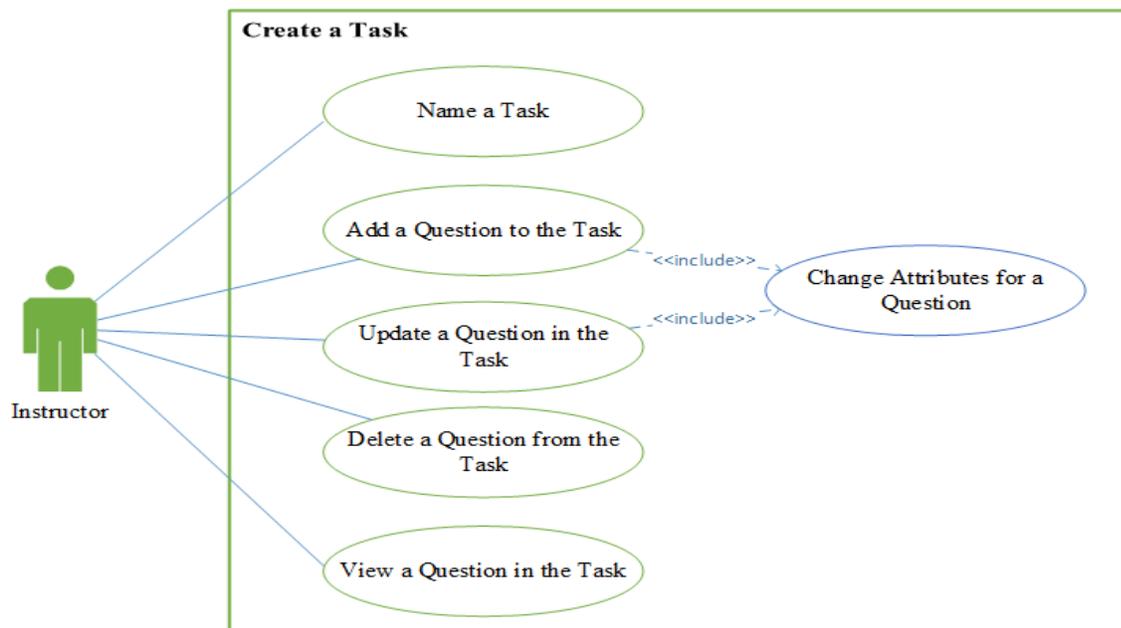
Figure A1. Creating a concept map task use case diagram

Figure A2 displays the assigning-a-concept-map-task use case. When an instructor wants to assign a concept map task, he or she can set some attributes for the task. For example, the instructor can set beginning date and due date for the task. The instructor can choose to assign the concept map task to the registering student accounts and email these students, or to generate a bunch of temporary student accounts and assign the task to these temporary student accounts.
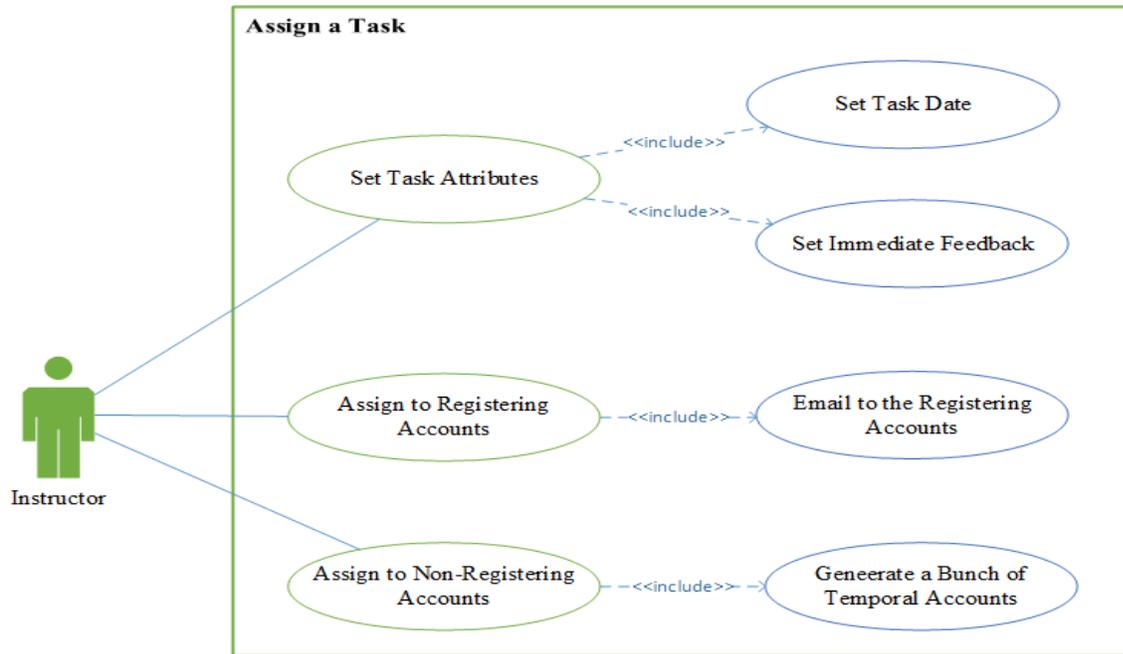
Figure A2. Assigning a concept map task use case diagram

Figure A3 shows the creating-an-expert-map-task use case. An instructor can create an expert map for a concept mapping question. The instructor can also update or delete the expert map. In addition, an instructor can edit weights for the propositions in an expert map as well as maintain a proposition pool for the expert map.
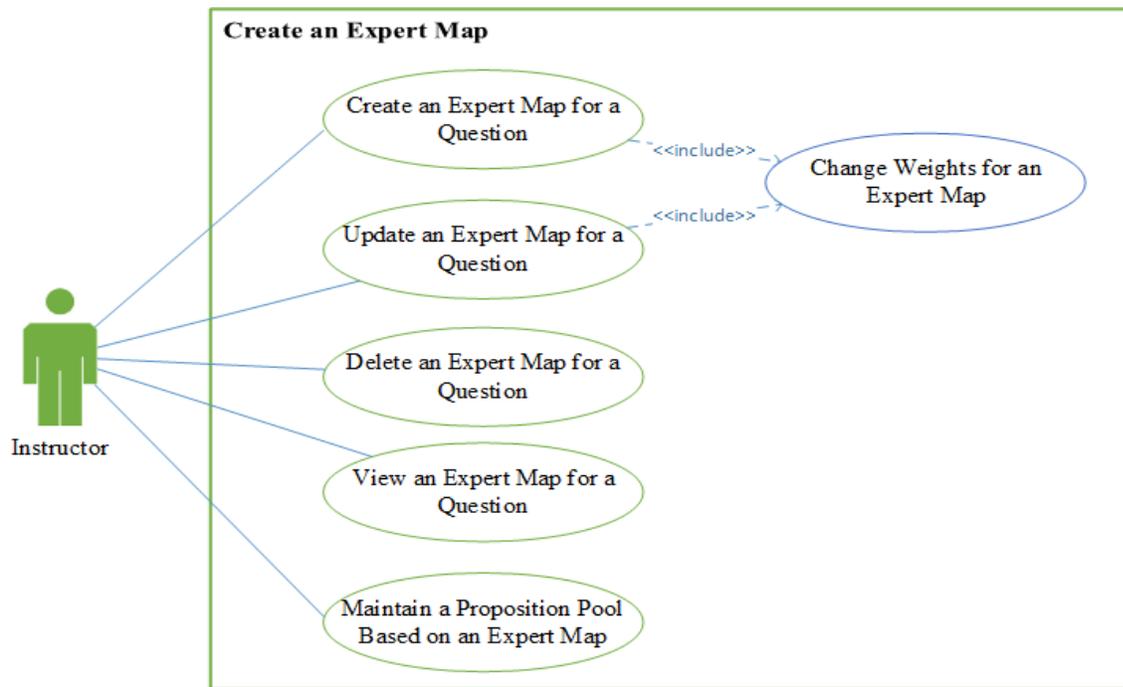
Figure A3. Creating an expert map use case diagram

Figure A4 displays the generating-a-knowledge-assessment-report use case. After the system auto-scores a student-created concept map, an instructor can check the auto-scoring result and tweak it if needed. The instructor can also write a brief summary for the result. In addition, an instructor can publish the report and email the report to the student.
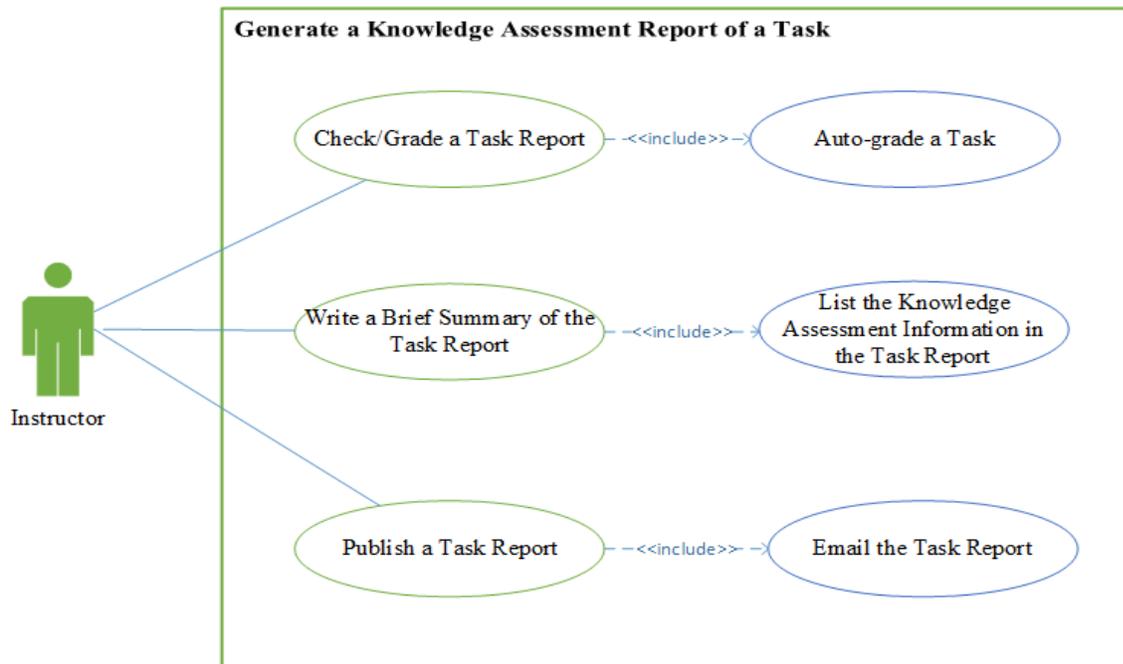
Figure A4. Generating a knowledge assessment report use case diagram

Figure A5 shows the taking-a-concept-map-task use case. A student user can resume an incomplete concept map task or start a new concept map task. A student user can also submit his or her concept map or cancel it.
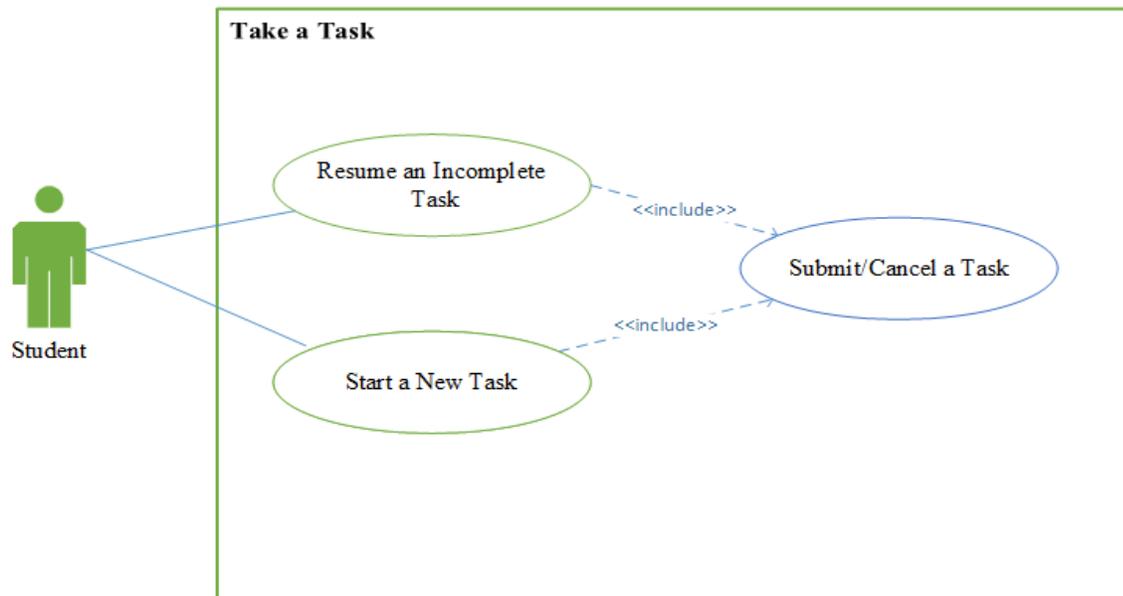
Figure A5. Taking a concept map task use case diagram

Figure A6 displays the viewing-a-knowledge-assessment-report use case. A student user can view the knowledge assessment report based on his or her submission. A student user can also download or export the knowledge assessment report.
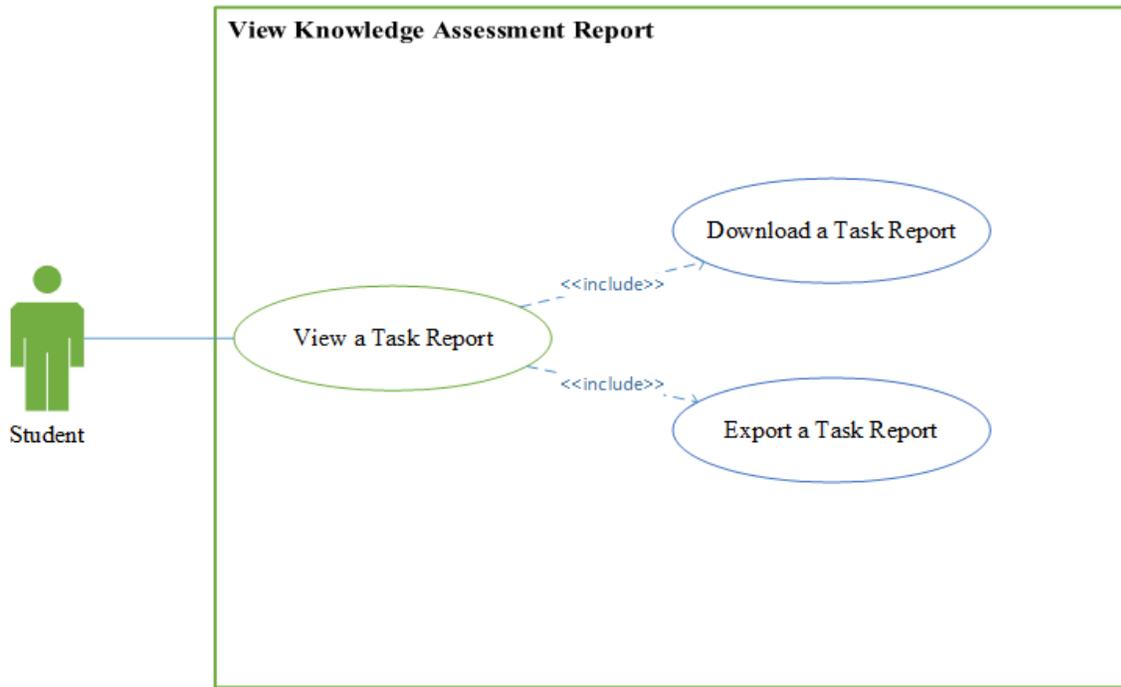
Figure A6. Viewing a knowledge assessment report use case diagram

Figure A7 displays the administrator dashboard use case. An administrator user can manage user accounts like student account and instructor account. An administrator can also monitor and manage the concept map task, the assessment and the report, as well as the database and system configuration.
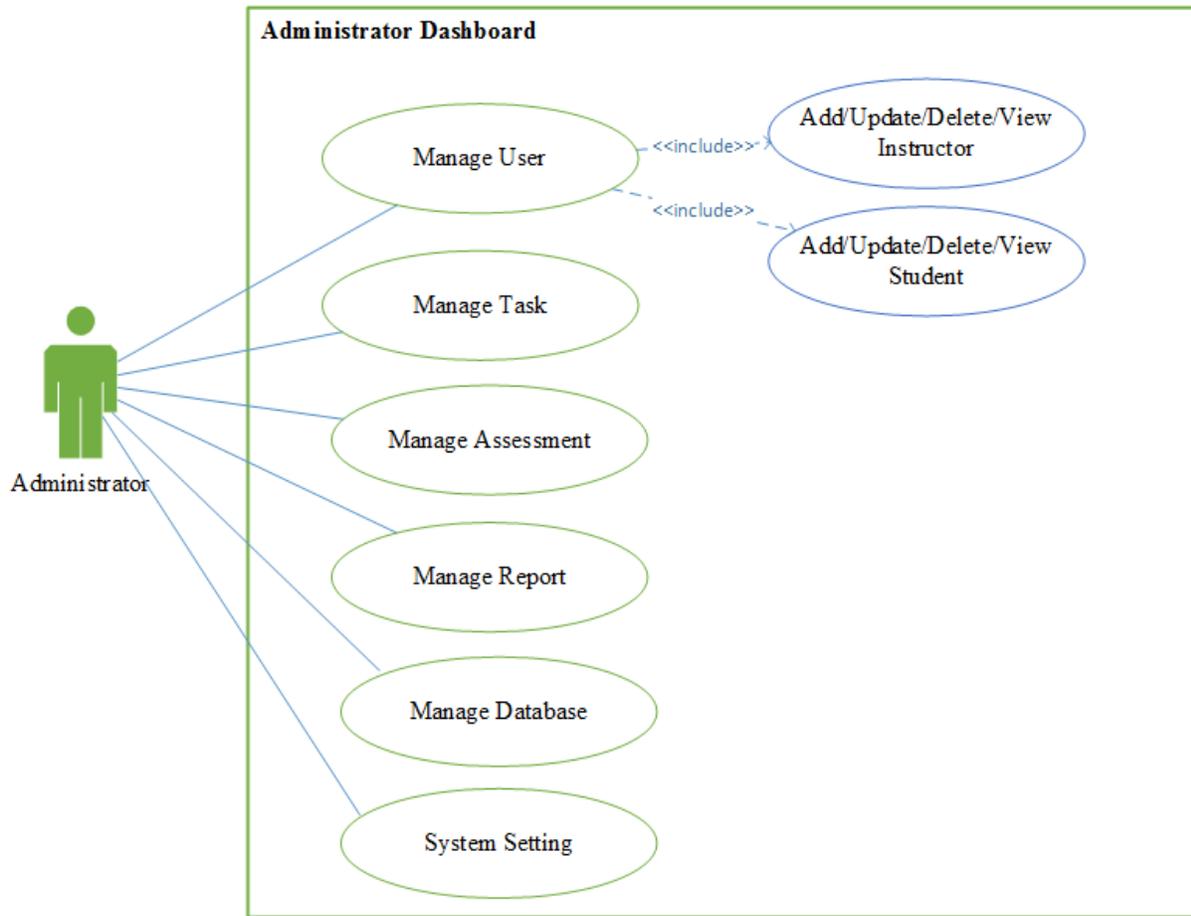
Figure A7. Administrator dashboard use case diagram

Appendix B: Interactions between Modules

The interaction for taking a concept map task. A student may interact with the user module and task module to take a concept map task. After registering the knowledge assessment system, the student logs into the system with a valid user account and password and obtains authenticated by the user module, then the student can select a concept map task which has been assigned to him or her by the instructor, and take the concept map, then submit his or her response. Figure B1 shows how a student takes a concept map task and submits his or her response.
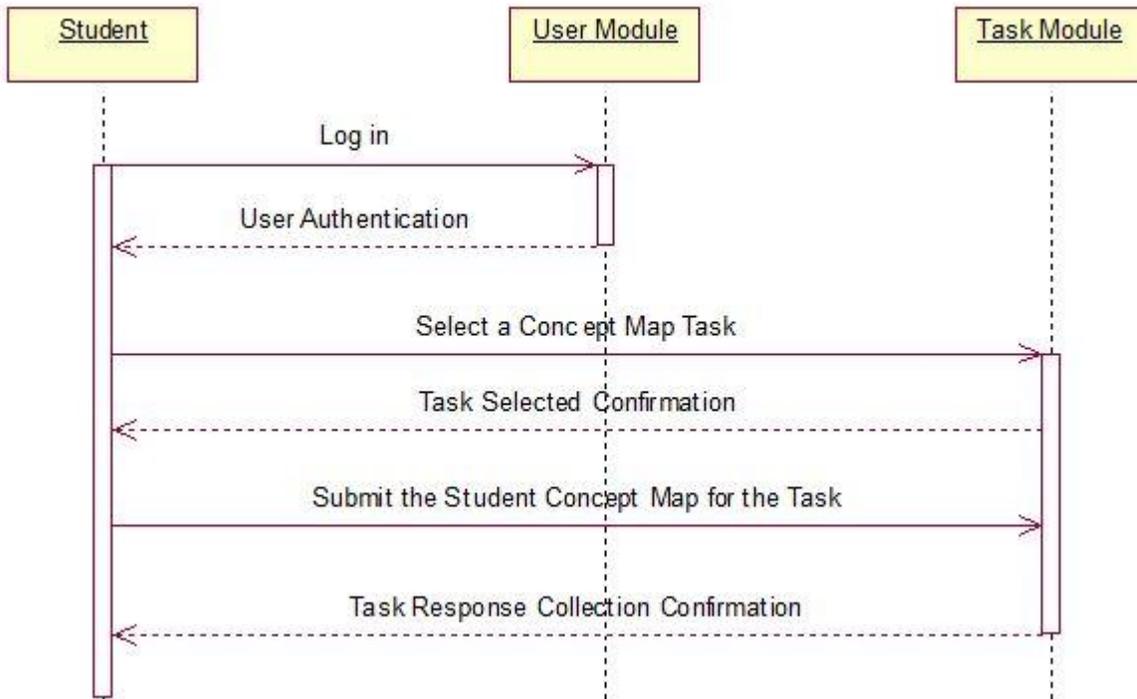
Figure B1. The interaction diagram of taking a concept map task

The interaction for requesting an assessment report for students. A student may interact with the user module, assessment module and report module to request an assessment report after submitting her or his concept maps. After logging into the system with a valid account, the student can request an assessment report, and the report module would check whether the assessment report is ready; if not ready, the report module would communicate with the assessment module to request

the auto-assessing results and generate the assessment report, then send the assessment report back,

Figure B2 shows how a student requests an assessment report.
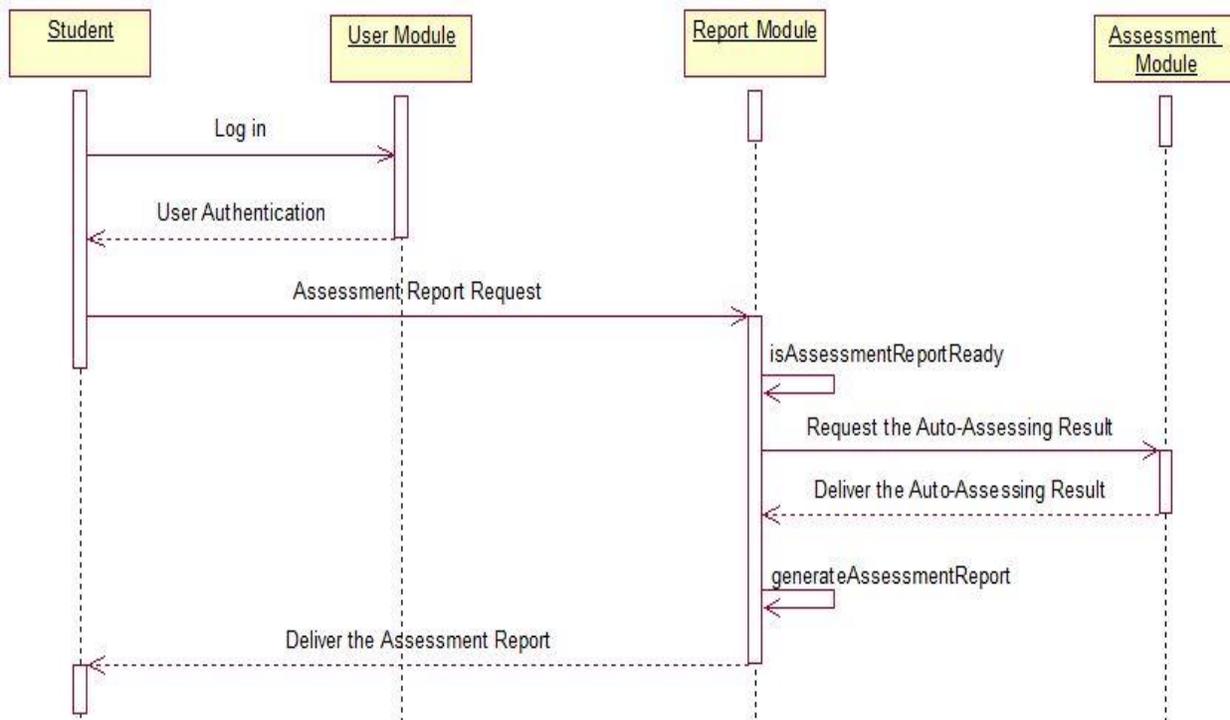
Figure B2. The interaction diagram of requesting an assessment report for a student

The interaction for requesting a report for instructors. An instructor may interact with the user module, assessment module and report module to request a report after the students have submitted their concept maps. After logging into the system with a valid account, the instructor can manage the assessment criterion like expert maps assigned weights and refine them. When the instructor requests the report, the report module would check whether the report is ready; if it is not ready, the report module would communicate with the assessment module and request all auto-assessing results of student concept maps, then generate a report and deliver the report to the instructor. Figure B3 shows how an instructor requests a report.
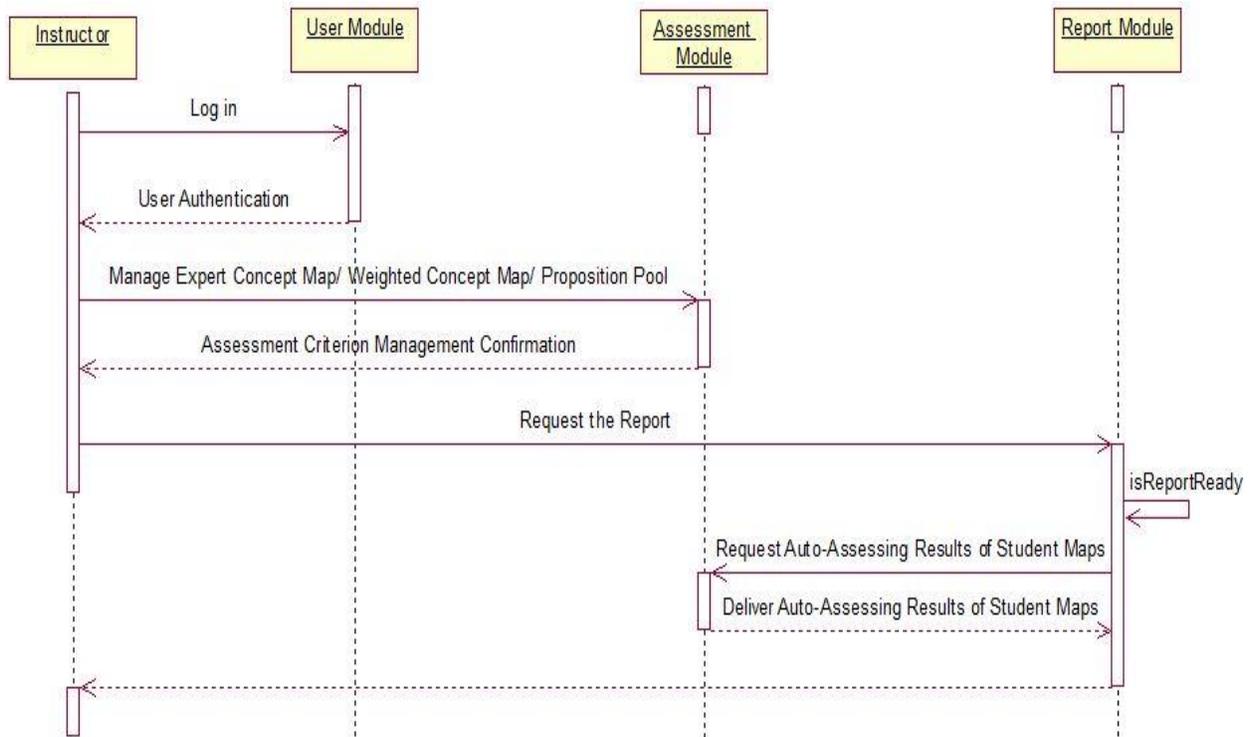
Figure B3. The interaction diagram of requesting a report for an instructor

The interaction for administration activities for an administrator. An administrator may interact with the user module, task module, assessment module and report module for administration purposes. After logging into the system with a valid account, an administrator can manage the user accounts, monitor the concept map tasks, the assessments and the reports. Figure B4 shows how an administrator communicates with the different modules.
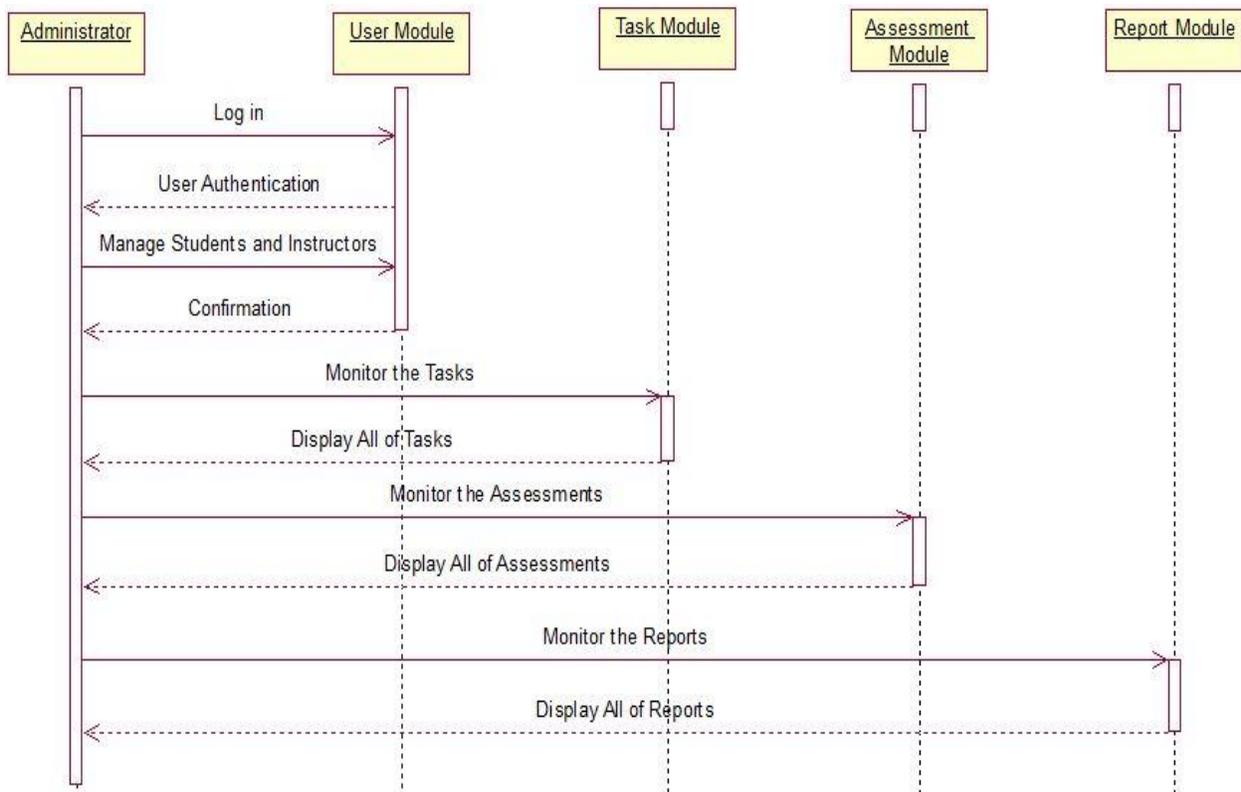
Figure B4. The interaction diagram of administration activities for an administrator

Appendix C: Component Design

Detailed design of task module. The task module is responsible for the task-related management. This module includes these functionalities: concept map task creation, adding a concept map question into a task, maintaining concept map questions, maintaining concept map tasks, assigning concept map tasks, taking concept map tasks and collecting concept map task response (see Figure C1 and Table C1).
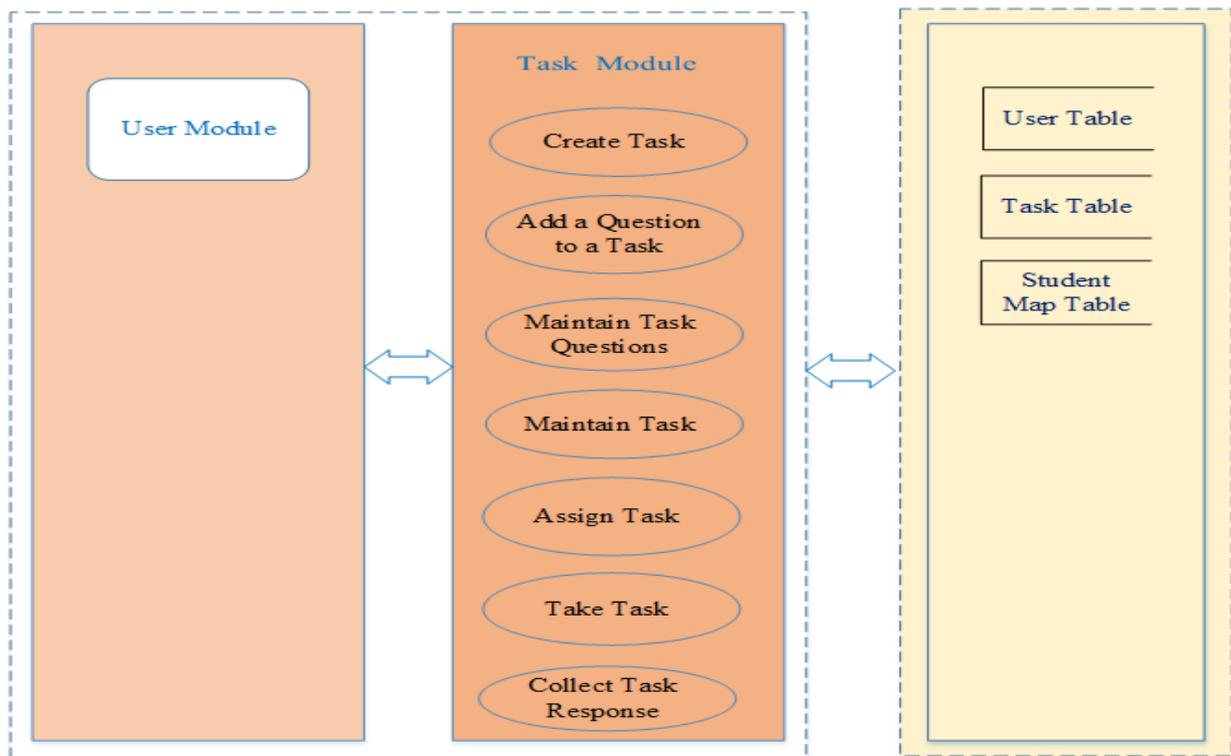
Figure C1. The detailed design of task module

Table C1. *The Description of the Detailed Functionalities of Task Module*

Function	Description
Create Task	An instructor can create a concept map task for students, including naming the concept map task, setting task policy as well as setting the beginning date and due date for the task.

Add a Question to a Task	An instructor can add a concept map question into the task. Right now four types of concept map task questions can be added: fill-in-a-concept-map with provided nodes, fill-in-a-concept-map with provided linking phrases, construct-a-concept-map with a partially pre-drawn one provided, and construct-a-concept-map with nothing provided.
Maintain Task Question	An instructor can edit or delete the task questions.
Maintain Task	An instructor can edit or delete the concept map tasks.
Assign Task	An instructor can publish a concept map task and assign the task to his or her students.
Take Task	The students who have valid user accounts can log into the system and take the tasks assigned to them.
Collect Task Response	After a student completes a concept map task and submits the response, the system would analyze and auto-assess the student's concept map, as well as store it into the database; the instructor can decide the undetermined propositions in the student's concept map to be correct or incorrect, and add them into the proposition pool.

Detailed design of assessment module. The assessment module is in charge of the

assessment-related aspects management. This module includes these functionalities: expert

concept map creation, maintaining expert concept map, adding weights for expert map,

maintaining weights for expert map, adding proposition pool, maintain proposition pool, auto-

assessing student map, and setting assessment feedback (see Figure C2 and Table C2)..
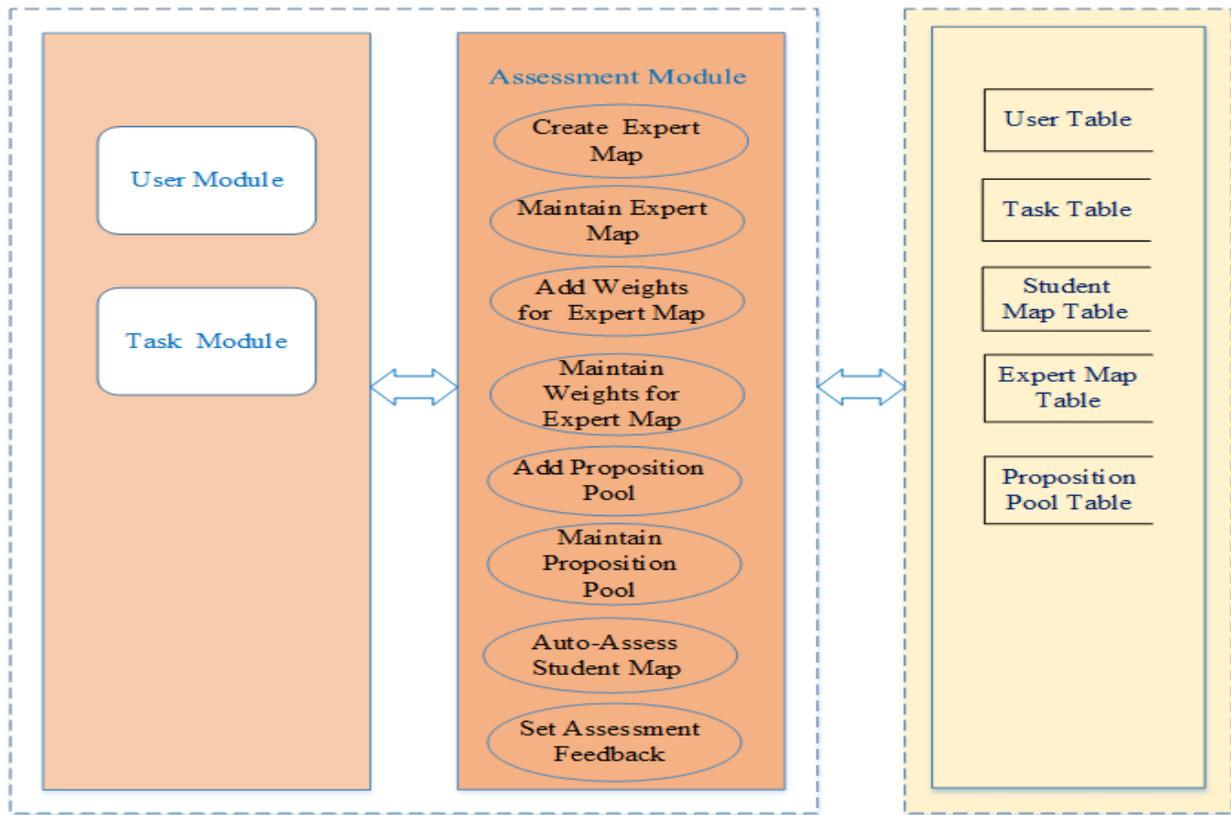
Figure C2. The detailed design of assessment module

Table C2. *The Description of the Detailed Functionalities of Assessment Module*

Function	Description
Create Expert Map	An instructor can create an expert concept map for each concept map question. The expert concept map will be used as a criterion for auto-assessing the students' concept maps.
Maintain Expert Map	An instructor can update or delete an expert concept map.
Add Weights for Expert Map	An instructor can add weights for an expert concept map. These weights will be used as another angle of the criterion for auto-assessing students' concept maps.
Maintain Weights for Expert Map	An instructor can update or delete the weights in an expert map.
Add a Proposition Pool	An instructor can add a proposition pool for improving the assessment criterion of a concept map task.

Maintain a Proposition Pool	An instructor can update or delete the proposition pool.
Auto-Assess Student Map	The assessment module will auto-assess the students' concept maps based on the assessment criteria.
Set Assessment Feedback	An instructor can set the assessment feedback for the students after they submit their concept maps. The feedback can be an instant feedback generated by the system or a summary feedback edited by the instructor.

Detailed design of report module. The report module is responsible for the student concept map report. This module includes these functionalities: student report generation, checking or editing student report, publishing student report, emailing report, viewing report, downloading report and exporting report (see Figure C3 and Table C3)..
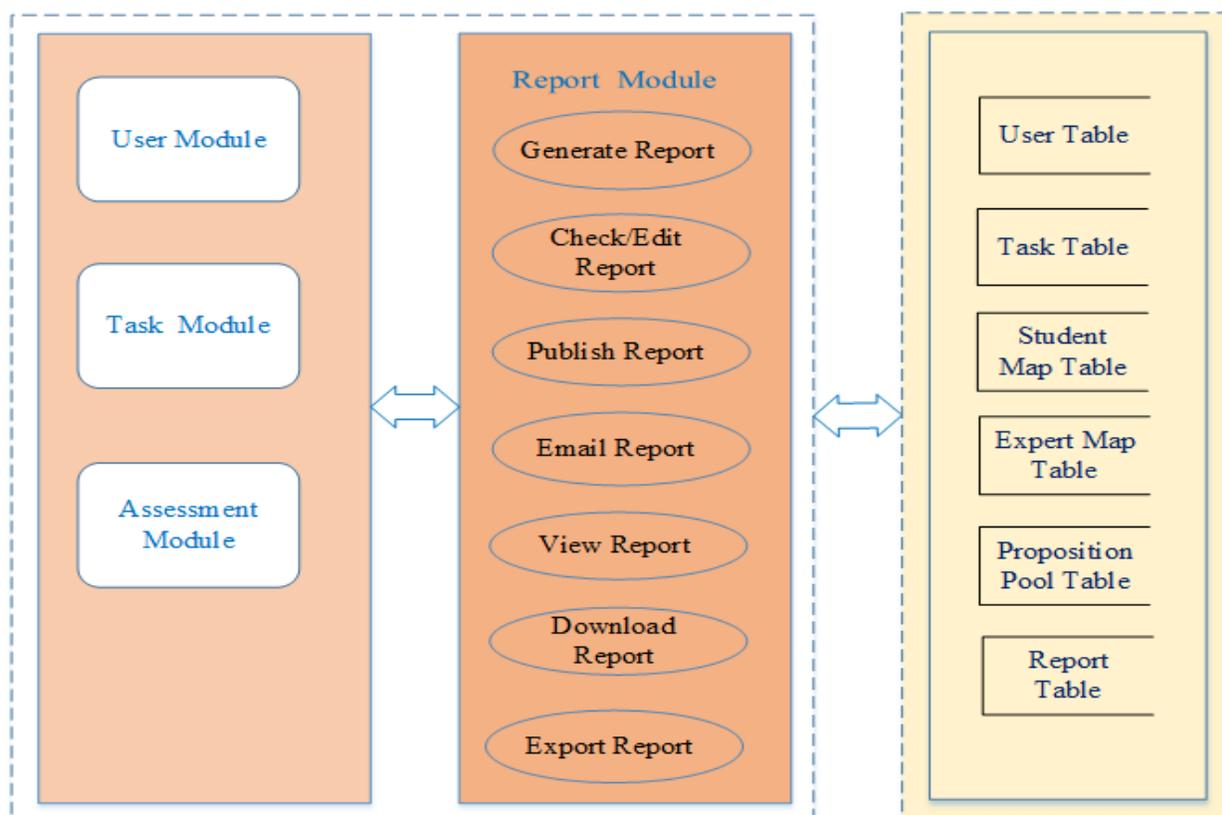
Figure C3. The detailed design of report module

Table C3. *The Description of the Detailed Functionalities of Report Module*

Function	Description
Generate Report	After a student submits his or her concept map, the report module is responsible for generating a timely assessment report on student's knowledge performance based on the submission.
Check/Edit Report	An instructor can check or edit any generated report for the students.
Publish Report	An instructor can publish a report when it is ready; a student can log into the system to view the report. If the report is set to be shown instantly, the instructor does not need to publish it; the student can obtain the report at once after his or her concept map has been submitted.
Email Report	An instructor can deliver the report to his or her students via email.
View Report	A student can view the report online after the report is published.
Download Report	A student or an instructor can download a report after it is ready.
Export Report	A student or an instructor can export a report as a PDF file or Word file after it is ready.

Detailed design of administration module. The administration module is in charge of

managing the other four modules, the database and the system configuration. This module

includes these functionalities: user management, task management, assessment management,

report management, system configuration, and system backup & update (see Figure C4 and

Table C4)..
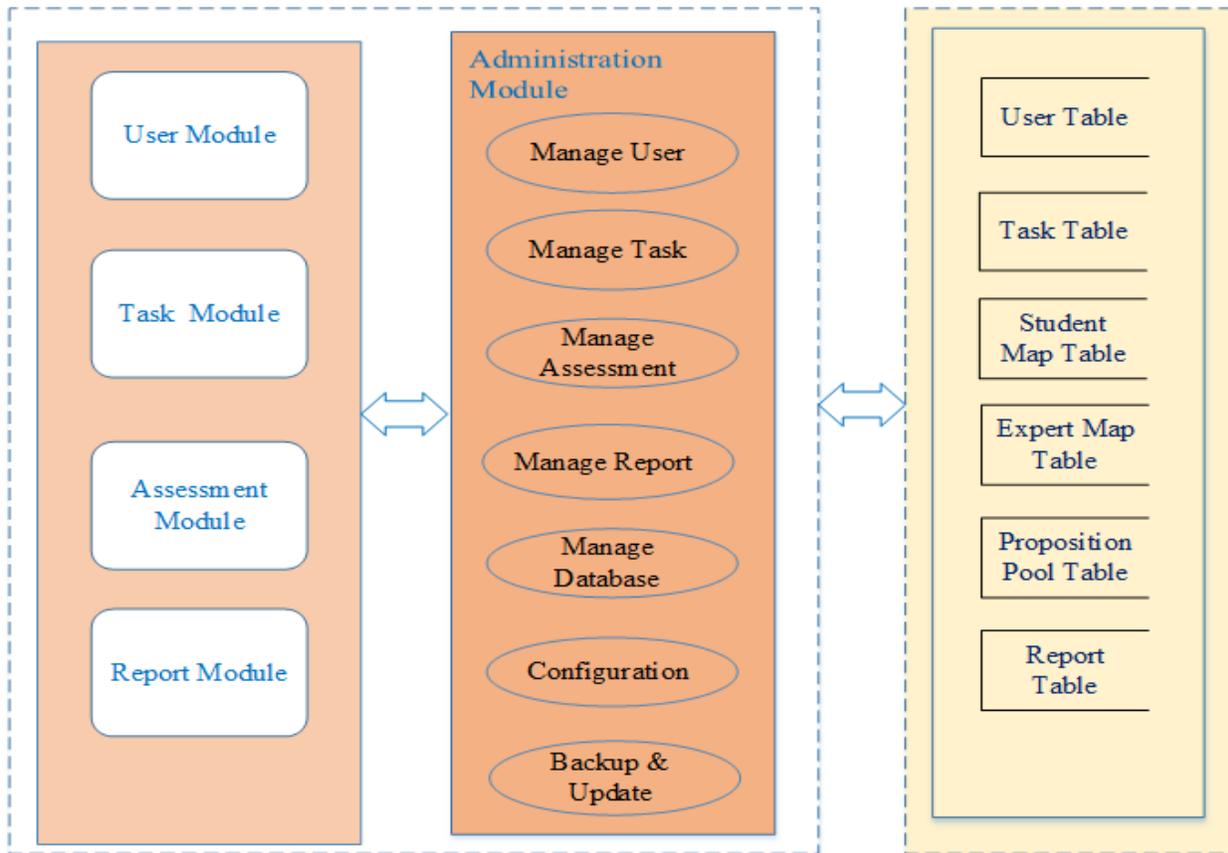
Figure C4. The detailed design of administration module

Table C4. *The Description of the Detailed Functionalities of Administration Module*

Function	Description
Manage User	An administrator can manage any student user account or instructor user account, including adding user account, updating the user profile, resetting user password and viewing the statistical information of user accounts.
Manage Task	An administrator can manage any concept map task, including creating a concept map task, changing its name, and setting its beginning date and due date. Although an administrator has the privilege to manage task, usually it is the instructor's job to manage concept map tasks for his or her course.
Manage Assessment	An administrator can manage any task assessment criteria, including creating an expert concept map, setting weights for the expert concept map, and managing the proposition pool. Although an administrator has this privilege to manage assessment, usually it is the instructor's job to manage the assessment criteria for his or her concept map tasks.

Manage Report	An administrator can manage any concept map task report, including checking or editing the report, publishing the report, delivering the report, downloading the report and exporting the report. Although an administrator has the privilege to manage report, usually it is the instructor's job to manage the concept map reports for his or her students.
Manage Database	An administrator can manage the database for the system, including adding database tables, updating database tables and querying any data from the database.
Configuration	An administrator can configure the system, including adding task question types, setting concept map task policies and setting APIs.
Backup & Update	An administrator can update the software patches at the back end and back up the database. .

Appendix D: Learning Materials for the Evaluation

Definition of concept maps. A concept map is a diagram consisting of nodes and labeled directional links. The nodes represent concepts, and the labeled directional links connecting nodes represent relationships between concepts (Novak, Gowin, & Johansen, 1983).

An example of concept map. See the following figure (Figure D1).
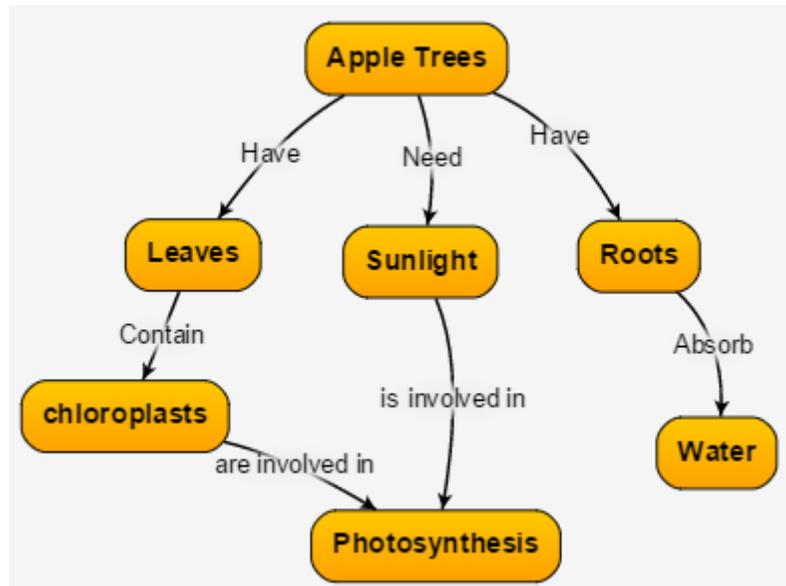
Figure D1. A concept map example

Components of concept maps.

• Nodes and links are the basic components of a concept map. A node consists of a node symbol and a node term. A node symbol can be a graphic shape like an oval or a circle. A node term is used to label a node. A node symbol and a node term are combined to represent a concept.

• A link is composed of a directional linking line and a linking phrase. A directional linking line is used to connect two nodes, which means there is a relationship between these two nodes. The arrowhead of the linking line indicates the direction of the relationship between the two nodes. A linking phrase labels the relationship.

• A combination of node-link-node is a proposition, which is a basic meaningful unit in a concept map.

In the above figure, the node "Apple Trees" is composed of an oval and the term "Apple Trees". "Need" is a linking phrase which is associated with a liking line, representing the relationship between the concepts of "Apple Trees" and "Sunlight". "Apple Trees - Need - Sunlight" is a proposition.

Two Types of Concept Map Tasks

Fill-in-a-concept-map task. This type of concept map task will provide node terms or linking phrases, require you to select the appropriate node terms or linking phrases, and input them in the proper positions to replace the question marks of the concept map (see Figure D2 and Figure D3).

　　• Select a node term or linking phrase from the provided material being assessed.
• Double click the question mark of the concept map to delete it, and replace it with the node term or linking phrase you have selected.
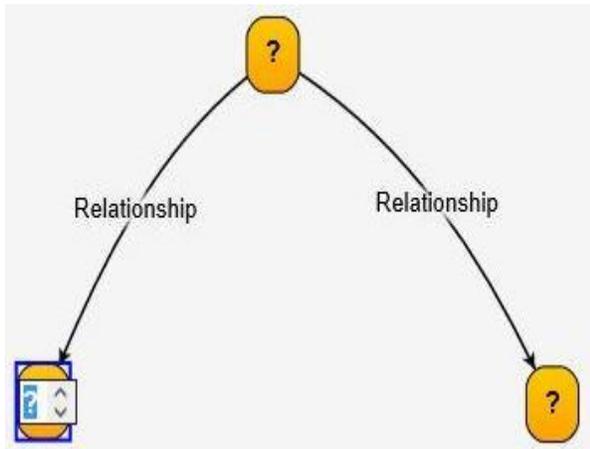
Figure D2. Fill-in-a-map with node
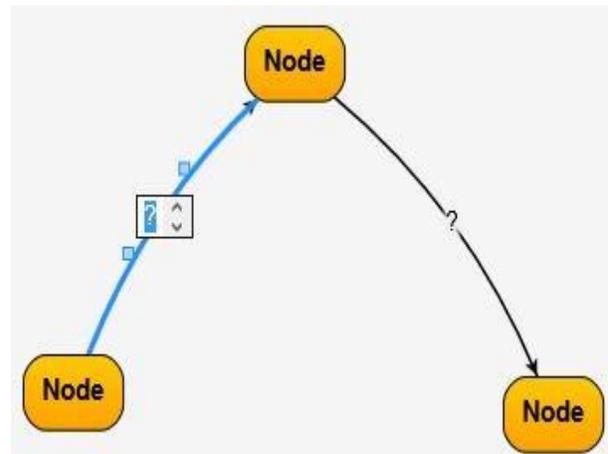
Figure D3. Fill-in-a-map with relationship

Construct-a-concept-map task. This type of concept map task will provide a partial concept map or none at all, and require you to create a concept map based on your understanding of the provided materials (see Figure D4 and Figure D5).
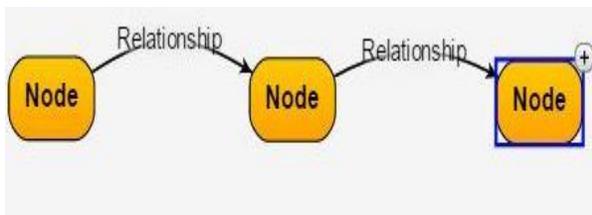
Figure D4. Add a new node
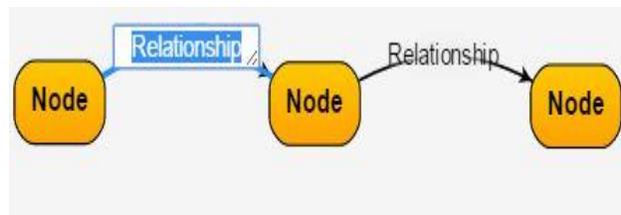
Figure D5. Edit a relationship

When creating a concept map using this system, the following operating actions may be included.

- **Adding nodes**. Click one node of the concept map, and a plus sign on the top-right corner will appear; click the plus sign to add a new node (see Figure D6).
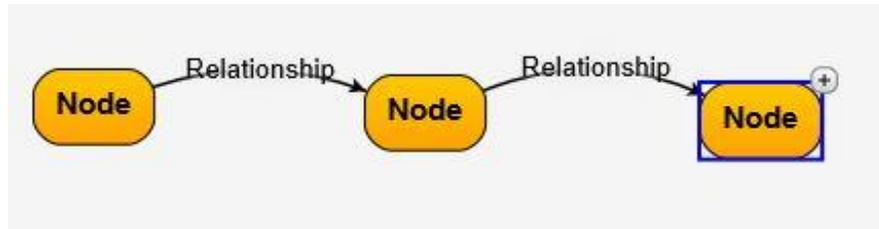
Figure D6. Construct a concept map - adding a node

- **Moving nodes**. Select one node that you want to move, then click your left mouse button down, make sure your cursor is *an arrow,* drag your mouse and you can drag the node. If your cursor is *a hand*, it will add a linking line (see Figure D7). .
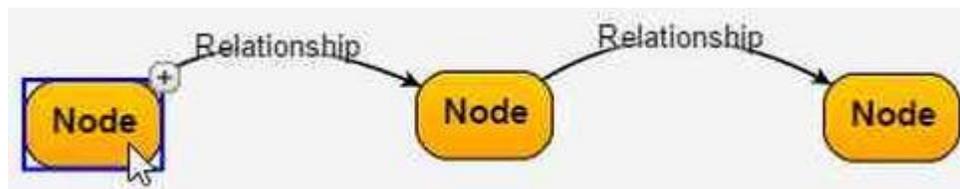
Figure D7. Construct a concept map – moving a node

- **Moving the whole concept map.** Click your mouse at any place in the editing region, then click your mouse left down, move your mouse to the target place (see Figure D8).
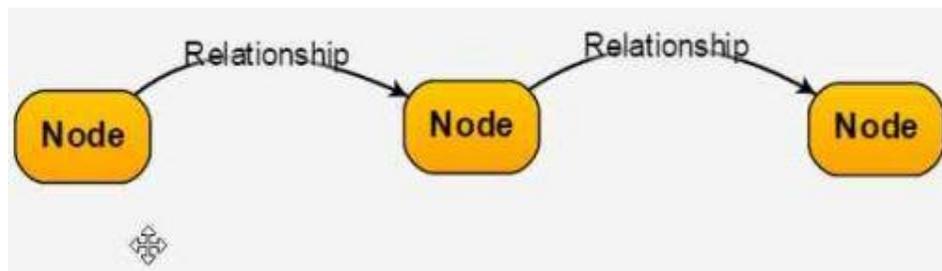
Figure D8. Construct a concept map – moving the whole concept map

- **Connecting nodes**. Select the starting node, then click your left mouse button down, make sure your mouse is a hand, drag your mouse from the starting node to the terminal node. A line between the two nodes and a term of relationship should appear (see Figure D9). .
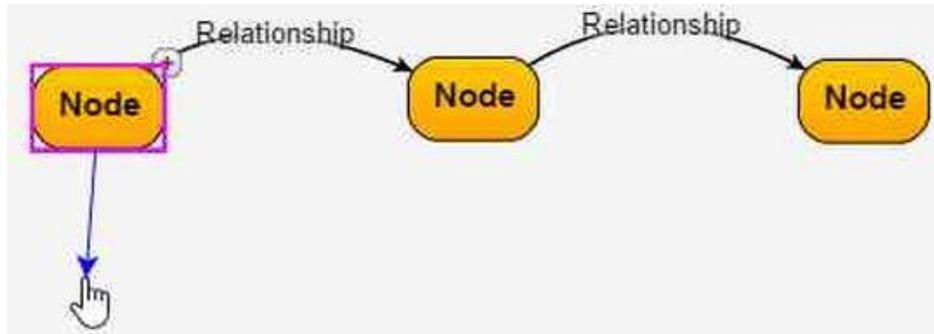
Figure D9. Construct a concept map – adding a linking line

- **Changing node terms or linking phrases**. Double-click your mouse on the node term or linking phrase, then it should become the editable status and allow you to input your node term and linking phrase. After changing, double click your mouse at other place to make sure it converts to a read-only status (see Figure D10). .
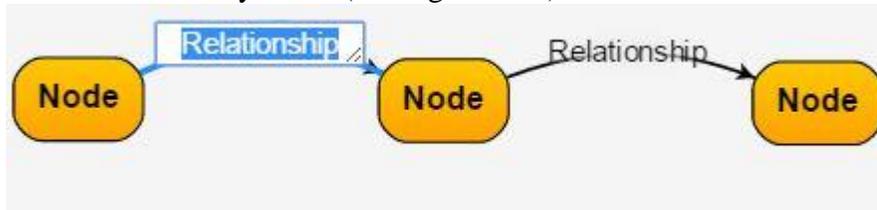
Figure D10. Construct a concept map – changing a linking phrase

- **Deleting a node or a linking line**. Select a node or a linking line which you want to delete, then press the *Fn+Delete* key on your keyboard.
- **Zooming in or zooming out your concept map**. Move your mouse's scroll wheel or use two finger swipe to zoom in or zoom out your concept map.
- **Resetting your concept map**. Click the Reset button under the editing region of your concept map to reset it.

The following three types of questions are designed for assessing students' factual knowledge, conceptual knowledge and procedural knowledge respectively. To make it straightforward, each question is used to assess one type of knowledge. These questions are already added into the system as a concept map task for your reference.

1. Please fill in the nodes of concept map based on your knowledge.

The concept map on the right side of this screen shows some of the US states and their abbreviations and capitals.

Please select the proper nodes from provided node list, and fill the nodes in the question mark positions of the concept map.

Note: First double click the question mark and delete it, then copy the appropriate node term from the Node List, and input it in the question mark position.

Node List:

Norfolk, Richmond, Boise, Clayton, Columbus, Houston, Akron, Douglas, Phoenix, Lansing, Buffalo, Detroit, Dover, MN, VA, VT, TX, WY, IL, GA, MI, TN, MO, WI, PA, OH, AZ, Vermont, Texas, Wisconsin, Iowa, Michigan, Pennsylvania, Missouri, Wyoming, Georgia (there are some distracters).
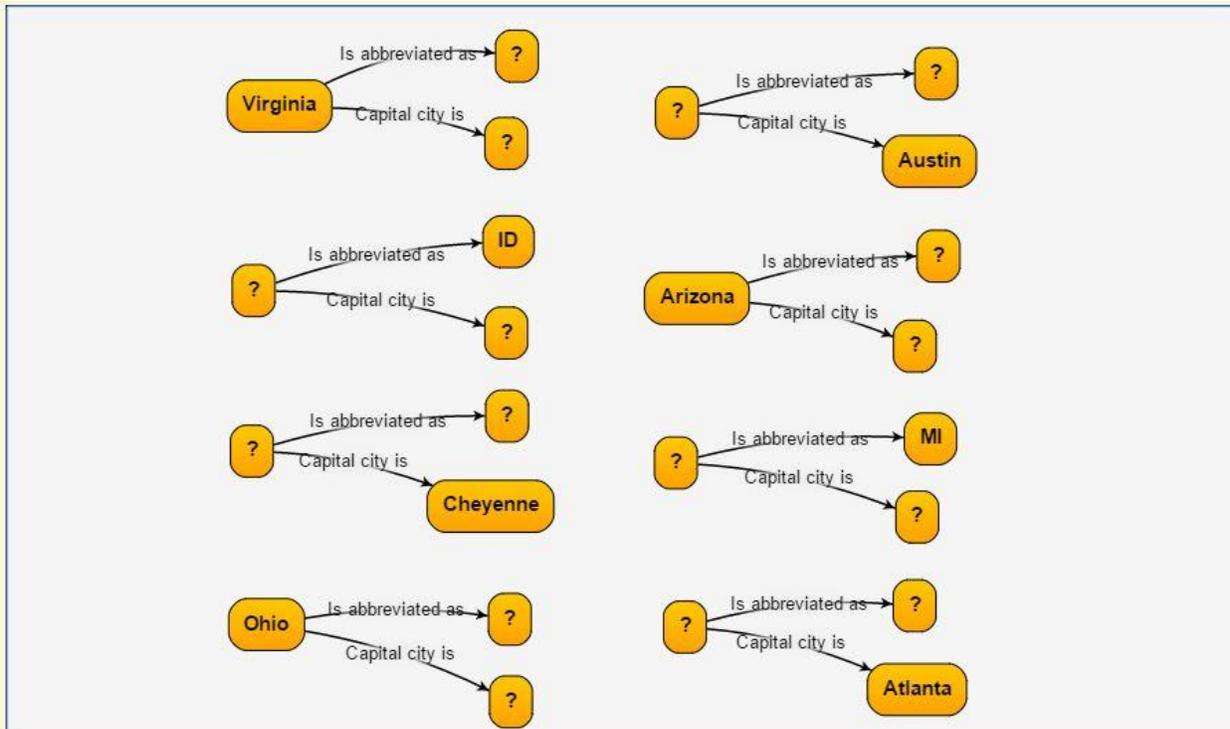
2. Please fill in the relationship of concept map based on your knowledge.

The concept map on the right side shows the relationships among the Sun, the Earth, and the Moon, as well as indicates some of the their characteristics.

Please select the proper linking phrases from the provided Relationship List, and fill them in the appropriate positions of the concept map.

Note: First double click the question mark and delete it, then copy the appropriate linking phrase from the Relationship List, and input it in the question mark position.

Relationship List:

Orbits, Rotates, Reflects, Gives out, Fuses, Has, Come from, Has small impact on, Has big impact on, Blocks, Absorbs, Refracts (there are some distracters).
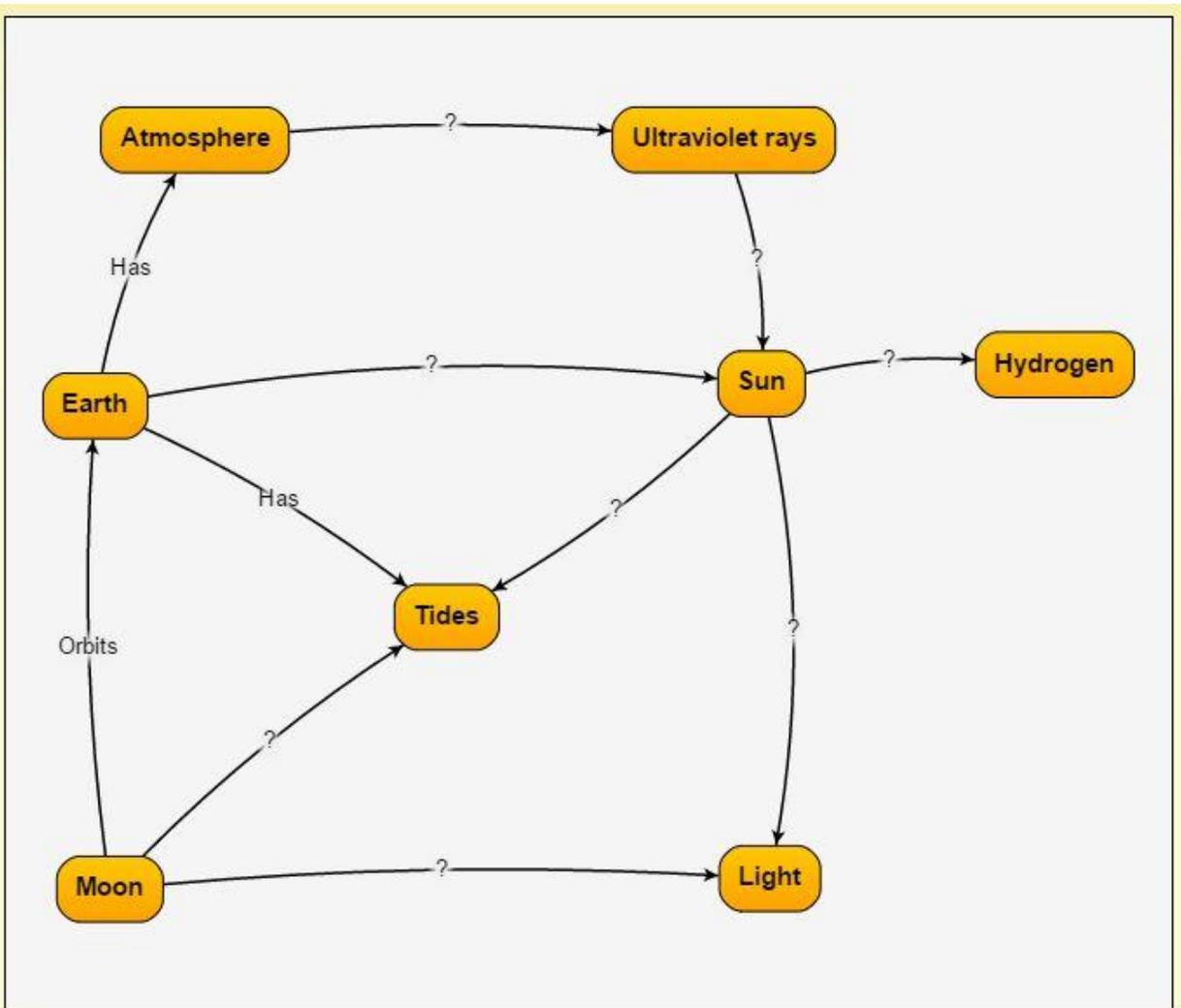
3. Please complete the concept map based on your knowledge of replacing a flat tire.

The provided concept map is a partial one of replacing a flat tire, please complete the concept map based on your knowledge. Suppose you have all of the essential tools.

Note: you can choose the proper nodes here (there are some distracters).

Remove the flat tire,

Jack up the vehicle,

Lower the vehicle and tighten the lug nuts,

Replace the wheel cover,

Put on the spare tire,

Replace the lug nuts and tighten them by hand,

Check the air pressure of the spare tire,

Remove the lug nuts,

Check the air pressure of the flat tire

The linking phrase between any two nodes is: Next

Appendix F: Step-by-Step Direction for Student Users to Evaluate the Knowledge Assessment System

The Knowledge Assessment System based on Concept Maps and Differential Weighting Approaches is a web-based system, which is designed to help instructors assess students' knowledge based on their completion of concept map tasks. In order to evaluate the system user interface and system functionality from the student user's perspectives, the following instructions and three sample tasks have been developed to allow student users to explore the system.

Task 1: Register the system as a student user.

- Click *Register* button on the home interface.
- Input a user name, password, first name, last name, email address and major field.
- Click the *Sign Up* button for registering the system; if canceling, click the *Cancel* button (see Figure F1).

Figure F1. The registering interface

Task 2: Log in and begin a concept map task.

- Log into the system with the user name and password you have created.
- Select a concept map task, and click the *Begin* hyperlink from the *Action* column (see Figure F2).

Concept Map Task Name	Open Time	Due Time	Action
Evaluation Concept Map Task	2015-06-19 18:00	2015-08-31 18:00	Begin
Evaluation-Concept Map Task	2015-06-12 15:38	2015-08-31 15:38	Begin
Example-Concept Map Task	2015-06-11 11:19	2015-07-31 11:19	Begin
Example-Concept Map Task	2015-06-18 18:23	2015-08-31 18:23	Begin
Example-Personal Health Concepts	2015-06-11 11:19	2015-07-31 11:19	Begin

Figure F2. Take a concept map task

- After you click the *Begin* hyperlink, you will enter the task question interface; click the *Complete* hyperlink to answer the concept map question (see Figure F3).
- If you want to edit your answer, click the *Edit* hyperlink to open the interface for editing your answer of the concept map question.

Task List > **Evaluation-Concept Map Task**

Question Title	Question Type	Action
Please select the proper node to replace the question mark and fill in the concept map.	1-Fill-in-a-concept-map, providing nodes	Done / Edit
Please select the proper linking phrase from the relationship list to fill in the concept map.	2-Fill-in-a-concept-map, providing relationship	Complete
Please complete the concept map to show the procedure of preparing an interview.	3-Construct-a-concept-map, providing partial one	Complete
Please construct a concept map to reflect your strengths and weaknesses as a fresh graduate job-seeker.	4-Construct-a-concept-map, providing nothing	Complete

Figure F3. Listing concept map question interface

- After you click the *Complete* hyperlink, you will enter the answering question interface where you can answer the question (see Figure F4).

Figure F4. Answering concept map question interface

Task 3: Request the assessment report.

- After you finish all of the questions of a concept map task, a *Request Report* button will appear; you can click the button to view your knowledge assessment report (see Figure F5).

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Figure F5. *Completing concept map question interface*

- After you click *Request Report* button, you will enter the interface of knowledge assessment report (see Figure F6).

Figure F6. *Knowledge assessment report interface*

Appendix G: Step-by-Step Direction for Experts to Evaluate the Knowledge Assessment System

The Knowledge Assessment System based on Concept Maps and Differential Weighting Approaches is a web-based system, which is designed to help instructors assess students' knowledge based on their completions of concept map tasks. In order to fully understand the system functions, the following instruction including eight tasks is developed to guide the subject-matter experts to explore the system.

Task 1: Create a concept map task.

- Log into the system as an instructor using the credential provided by the researcher.
- In the concept map task interface, click *Add Task* button on the right side of the interface.
- Input a task name, open time, due time, and check the checkbox to publish the task.
- Click the *Save* button for saving the concept map task; if canceling the task, click the Cancel button (see Figure G1).

Figure G1. Create a concept map task

Task 2: Edit a concept map task.

- In the concept map task interface, click *Edit* hyperlink from the *Action* column (see Figure G2).
- Edit the task name, open time, due time, and the checkbox to publish the task.
- Click the *Save* button for updating the concept map task; click the *Cancel* button for canceling the updating of the task.
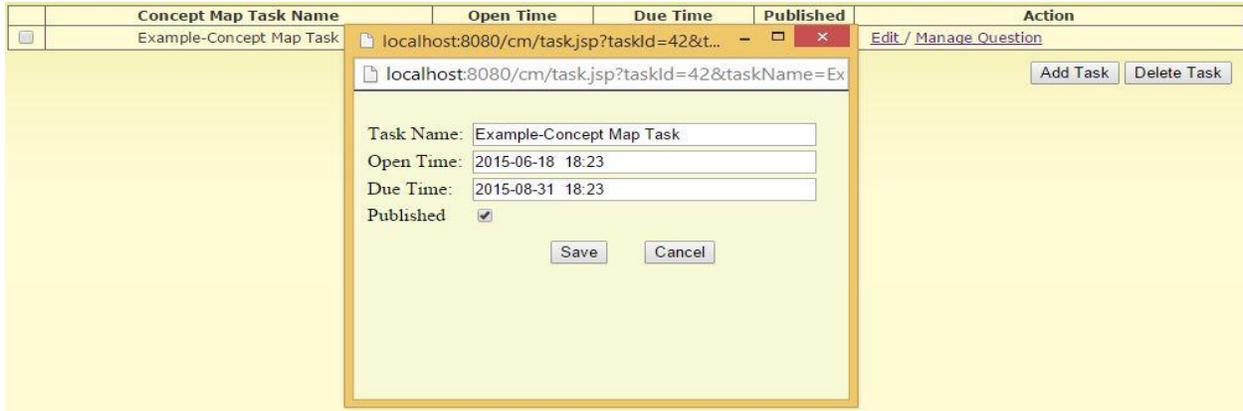
Figure G2. Edit a concept map task

Task 3: Delete a concept map task.

- In the concept map task interface, check the checkbox for preparing to delete the concept map task (see Figure G3).
- Click the *Delete Task* button on the right side of the interface for completing the deletion.
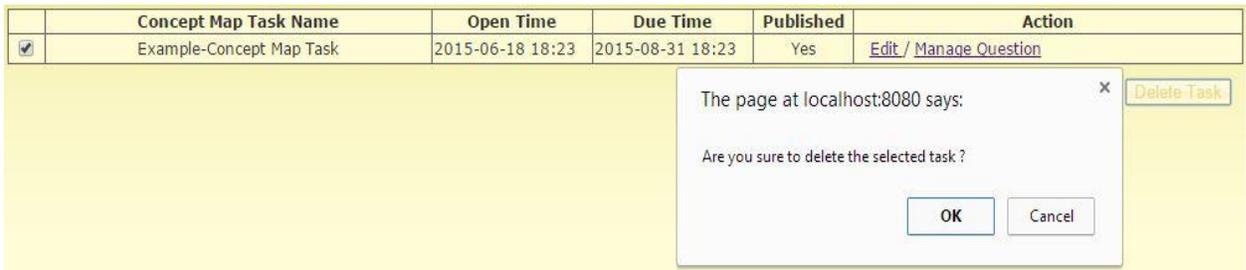
Figure G3. Delete a concept map task

Task 4: Add a question into a concept map task.

- In the concept map task interface, click the *Manage Question* hyperlink to open the interface for managing questions in a concept map task.
- In the interface of managing concept map question, click *Add Question* button to add a question for the concept map task (see Figure G4).

Figure G4. Managing concept map question interface

- In the interface of adding a question, select a *Question Type*, input a *Question Title*, select the *Knowledge Type*, input the *Question Content*, edit the incomplete concept map which will show in student interface, and check the checkbox of *Publish Question* (*there are four options for Question Type and Knowledge Type respectively. In this review, we recommend to respectively select the first three, which are set by default. We will conduct future research for designing a concept map question to assess students' metacognitive knowledge*) (see Figure G5).
- Click the *Save* button for saving the concept map question; click the *Cancel* button for canceling the concept map question; and click the *Close* button for closing the interface.

Figure G5. Add a concept map question

Task 5: Edit a question in a concept map task.

- In the interface of managing questions for a concept map task, click the *Edit* hyperlink from the *Action* column (see Figure G4).
- Edit the *Question Type*, the *Question Title*, the *Knowledge Type*, the *Question Content*, the incomplete concept map which will show in student interface, check or uncheck the checkbox of *Publish Question*.
- Click the *Save* button for updating the concept map question; click the *Cancel* button for canceling the updating of concept map question; click the *Close* button for closing the interface (see Figure G6).

Figure G6. Edit a concept map question

Task 6: Delete a question in a concept map task.

- In the interface of managing questions, check the checkbox for preparing to delete the question in a concept map task (see Figure G7).
- Click the *Delete Question* button on the right side of the interface for completing the deletion.

Figure G7. Delete a concept map question

Task 7: Manage an expert map for a question.

- In the interface of managing questions, click the *Expert Map* hyperlink from the *Action* column (see Figure G4).
- In the *Expert Map* interface, you can add or edit the expert map for a concept map question. The expert map will be used as the assessment criterion for the question.
- If assigning weights, add * sign at the end of a node term or linking phrase, then add the weight data; If deleting a node or linking phrase, select it and then press the *Fn+Delete* key on your keyboard.
- Click the *Save* button for saving the expert concept map; click the *Cancel* button for canceling it; click the *Close* button for closing the interface (see Figure G8).

Figure G8. Add or edit an expert map for a concept map question

Task 8: Score the students' knowledge and view the knowledge assessment report.

- You need to log in with a student credential which is provided by the researcher.
- In the student interface, you can act as a student to take the concept map task which you have created; after completing all of questions in the task, a *Request Report* button will appear; you can click the button to view the knowledge assessment report as a student user (**see the step-by-step instruction for student users**).
- If you want to score and view the knowledge assessment report, logging in the system with an instructor credential, you will find the *View Report* hyperlink, which is at the *Action* column (see Figure G9).

	Concept Map Task Name	Open Time	Due Time	Published	Action
☐	Evaluation-Concept Map Task	2015-06-12 15:38	2015-08-31 15:38	Yes	Edit / Manage Question / View Report
☐	Example-Concept Map Task	2015-06-11 11:19	2015-07-31 11:19	Yes	Edit / Manage Question / View Report
☐	Example-Personal Health Concepts	2015-06-11 11:19	2015-07-31 11:19	Yes	Edit / Manage Question / View Report

Add Task   Delete Task

Figure G9. Managing concept map task interface

- Click the *View Report* hyperlink, a new interface will be open for listing all of the students' information for completing the concept map task.
- In the report list interface, click the *View* hyperlink from the *View Report* column to open the knowledge report interface (see Figure G10).

Task List > **Evaluation-Concept Map Task Report**

User Name	Student Name	Student Email	Student Major	Task Name	View Report
student	Tao Congwu	skyely@126.com	IDT	Evaluation-Concept Map Task	View

Back

Figure G10. Listing interface for viewing student's report

- In the knowledge report interface, click the *Non-Weighting* button to view the knowledge assessment report without weights; click the *Weighting* button to view the knowledge assessment report with weights (see Figure G11).

Knowledge Assessment Report   [Non-Weighting] [Weighting]

Student Name	Tao Congwu
Task Name	Example-Personal Health Concepts
Task Taken Time	2015-04-26 20:02 - 2015-04-30 22:13

Factual Knowledge (Fill-in-Concept-Map with Providing Nodes)

Student's Proposition	Expert's Proposition	Assessment
Health Consciousness-Prevents-Diseases	Health Consciousness-Prevents-Diseases	Correct
Health Consciousness-Is Improved by-Health Education	Health Consciousness-Is Improved by-Health Education	Correct
Diseases-Reduces-Balanced Diet	Diseases-Reduces-Life Span	Incorrect
Life Span-Increases-Balanced Diet	Balanced Diet-Increases-Life Span	Incorrect
Health Education-Benefits-Life Span	Health Education-Benefits-Balanced Diet	Incorrect
Number of Correct Response: 2	Number of Incorrect Response: 3	
Percent of Correct Numbers: 40.0%	Percent of Incorrect Numbers: 60.0%	

Conceptual Knowledge (Fill-in-Concept-Map with Providing Linking Phrases)

Student's Proposition	Expert's Proposition	Assessment
Health Education-Benefits-Balanced Diet	Health Education-Benefits-Balanced Diet	Correct
Balanced Diet-Increases-Life Span	Balanced Diet-Increases-Life Span	Correct
Health Consciousness-Benefits-Health Education	Health Consciousness-Is Improved by-Health Education	Incorrect
Diseases-Relatitionship-Life Span	Diseases-Reduces-Life Span	Incorrect
Health Consciousness-Reduces-Diseases	Health Consciousness-Prevents-Diseases	Incorrect
Number of Correct Response: 2	Number of Incorrect Response: 3	

Procedural Knowledge (Construct-a-Map, Providing a Partial Pre-drawn One)

Source Node	Linking Phrase	Target Node	Assessment	
Health Consciousness	Reduces	Diseases	Different	Assess
Diseases	Reduces	Life Span	Correct	
Health Consciousness	Is improved by	Health Education	Missing	
Health Consciousness	Prevents	Diseases	Missing	
Number of Correct Response: 1		Number of Incorrect Response: 0		
Number of Different Response: 1		Number of Missing Response: 2		
Percent of Correct Numbers: 25.0%		Percent of Incorrect Numbers: 0.0%		
Percent of Different Numbers: 25.0%		Percent of Missing Numbers: 50.0%		

Metacognitive Knowledge (Construct-a-Map, Providing Nothing)

Source Node	Linking Phrase	Target Node	Assessment	
Health Consciousness	Enhances	Balanced Diet	Different	Assess
Exercises	Impacts	Life Span	Different	Assess
Health Education	Increases	Life Span	Different	Assess
Balanced Diet	Influences	Exercises	Different	Assess
Health Education	Benefits	Balanced Diet	Correct	
Health Consciousness	Is Improved by	Health Education	Correct	
Balanced Diet	Increases	Life Span	Missing	
Health Consciousness	Prevents	Diseases	Missing	
Diseases	Reduces	Life Span	Missing	
Number of Correct Response: 2		Number of Incorrect Response: 0		
Number of Different Response: 4		Number of Missing Response: 3		

Figure G11. Viewing knowledge assessment report

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- In the knowledge report interface, for assessing the *Different* proposition, click the *Assess* button to open a small interface for determining the proposition to be correct or incorrect, to be assigned weights or not, then click the *Confirm* button for saving the assessment; click the *Cancel* button for cancelling the assessment (see Figure G12) .

Figure G12. Assessing the Different proposition

Appendix H: Survey Questions for Student Users (*adapted from Liu, 2010*)

I. Participant Background
1. Do you have any experience of using a knowledge assessment system?   Yes / NO
2. Do you have any experience of evaluating a web-based system?   Yes / NO
3. Which grade are you in? Undergraduate/ Graduate /Other _____
4. Which Operating System (OS) are you using for completing the evaluation?
5. Which Web Browser are you using for completing the evaluation?

2. Using System (*1=strongly disagree, 2=disagree, 3=agree, 4= strongly agree*)

6. The information on each interface is easy to read.	1	2	3	4
7. The color arrangement on each interface helps provide a clear display.	1	2	3	4
8. The font size and style on each interface are appropriate.	1	2	3	4
9. It is easy to find the needed information on each interface.	1	2	3	4
10. The different information settings are clearly separated from one another.	1	2	3	4
11. The functions of buttons and menus work correctly.	1	2	3	4
12. The concept map task function is easy to follow.	1	2	3	4
13. The concept map questions are arranged in a good structure.	1	2	3	4
14. It is easy to add node terms or linking phrase terms in a fill-in-map task.	1	2	3	4
15. It is easy to change node terms or linking phrase terms in a fill-in-concept-map task.	1	2	3	4
16. For construct-a-concept-map task, it is easy to create nodes or linking phrases.	1	2	3	4
17. For construct-a-concept-map task, it is easy to remove node or linking phrases.	1	2	3	4
18. For construct-a-concept-map task, it is easy to change the directional linking line.	1	2	3	4
19. It is easy to rearrange and reorganize a concept map.	1	2	3	4
20. It is easy to zoom in or zoom out a concept map with mouse.	1	2	3	4
21. The knowledge assessment report is structured well and easy to understand.	1	2	3	4
22. The knowledge assessment report provides useful information about what kinds of knowledge I have grasped.	1	2	3	4
23. The icons are consistent among all of the interfaces.	1	2	3	4
24. The color arrangements are consistent among all of the interfaces.	1	2	3	4
25. The font size and style are consistent among all of the interfaces.				
26. The text menus are consistent among all of the interfaces.	1	2	3	4
27. The layouts are consistent among all of the interfaces.	1	2	3	4
28. The same categories of information have consistent location on the interfaces.	1	2	3	4

29. Do you have any comments or suggestions about the Knowledge Assessment System based on concept maps?

Appendix I: Survey Questions for Experts

1=strongly disagree, 2=disagree, 3=agree, 4= strongly agree

1. Given an appropriate question, the system can support a student's creation of a concept map responding to the question.	1	2	3	4
2. Given propositions contained in a student's concept map, the system can assess the student's *factual knowledge* based on a comparison of the student's propositions with the propositions of an expert.	1	2	3	4
3. The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *factual knowledge*.	1	2	3	4
4. The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in the expert map) for assessing student's *factual knowledge*.	1	2	3	4
5. The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *factual knowledge* based on the concept map question.	1	2	3	4
6. Comments for Question 2,3,4,5				
7. Given propositions contained in a student's concept map, the system can assess the student's *conceptual knowledge* based on a comparison of the student's propositions with the propositions of an expert.	1	2	3	4
8. The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *conceptual knowledge*.	1	2	3	4
9. The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in the expert map) for assessing student's *conceptual knowledge*.	1	2	3	4
10. The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *conceptual knowledge* based on the concept map question.	1	2	3	4
11. Comments for Question 7,8,9,10				
12. Given propositions contained in a student's concept map, the system can assess the student's *procedural knowledge* based on a comparison of the student's propositions with the propositions of an expert.	1	2	3	4
13. The Expert Map component of the system contains a function that can support the use of a non-weighting approach for assessing student's *procedural knowledge*.	1	2	3	4
14. The Expert Map component of the system contains a function that can support the use of a weighting approach (assigning weights to nodes or linking phrases in expert map) for assessing student's *procedural knowledge*.	1	2	3	4

15. The Knowledge Report component of the system contains a function that can support an instructor's assessment of the undetermined propositions (the different propositions in the knowledge report for assessing student's *procedural knowledge*) coming from students' concept maps to be either correct or incorrect, as well as assign them weights for future assessment.	1	2	3	4
16. The Knowledge Report component of the system contains a function that reports to what extent the students have mastered the *procedural knowledge* based on the concept map question.	1	2	3	4
17. Comments for Question 12,13,14,15,16				

18. Do you have any other comments or suggestions about the Knowledge Assessment System based on concept maps?

Appendix J: IRB Approval

VirginiaTech

MEMORANDUM
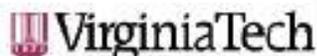
DATE:	July 6, 2015
TO:	Ken Potter, Congwu Tao
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE:	Development of a Knowledge Assessment System Based on Concept Maps and Differential Weighting Approaches
IRB NUMBER:	15-497

Effective July 2, 2015, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	Exempt, under 45 CFR 46.110 category(ies) 2,4
Protocol Approval Date:	May 18, 2015
Protocol Expiration Date:	N/A
Continuing Review Due Date*:	N/A

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

—— Invent the Future ——