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CONCEPT MAP-BASED KNOWLEDGE ASSESSMENT TASKS AND THEIR SCORING CRITERIA: AN OVERVIEW

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Abstract. Concept map is a graphical representation of its creator's knowledge structure, and it can be used as a tool for knowledge assessment. Even when considering only three factors – whether the structure, linking phrases and concept labels are given – there is a wide range of possible concept map-based tasks. Tasks with different demands allow assessing different aspects of knowledge, and thus, various sets of criteria are used for their assessment. Scoring of some of these criteria is easy to automate (e.g. count of concepts or propositions), but also more elaborate criteria are used that are more difficult to assess automatically (e.g. proposition's depth of explanation). This paper represents the results of a literature study on usage of concept map-based tasks for knowledge assessment purposes and criteria used to score them.

1 Introduction

Human memory is an interrelated system, and learning process is described as an alteration of this system by adding new knowledge pieces and/or modifying the structure to accommodate newly learned knowledge. Knowledge assessment allows measuring the outcomes of learning and determines whether the educational process has been successful. As knowledge structure cannot be observed directly, various indirect methods are used instead. Concept maps (CM) are one of such methods.

CM is a graphical tool for representing knowledge structure in a form of a graph whose nodes represent concepts, and arcs between nodes correspond to interrelations between them. Linking phrases on the arcs describe the semantics of a connection. Two concepts and a relationship between them form a proposition. None of the concepts can be explained without referring to its relation to other concepts (Ruiz-Primo & Shavelson, 1996), so the proposition is the smallest unit of meaning in CMs. The more knowledge one holds in the domain, the more interconnected the responding knowledge structure is. Concept maps can have hierarchical segments with cross-links between these segments or a net-like structure where other kinds of relationships dominate.

Since 1970's, when Concept maps (CM) were introduced as a pedagogical tool (Novak & Cañas, 2006), researchers have experimented with a wide range of CM-based tasks to test their suitability for knowledge assessment purposes. According to Ruiz-Primo & Shavelson (1996), a CM-based task consists of three main parts: task demands, task constraints and task content structures. Task demands define what a student has to do to complete the task: construct a CM, fill in missing elements in a CM structure, rate the relatedness of concept pairs etc. Task constraints (directedness of the task) refer to the limitations that a student has to follow while solving a task. For example, a student may be asked to use only the concept labels and linking phrases given in a list or define them himself/herself. Task content structure refers to the nature of the subject domain to be mapped. There are hierarchical domains, e.g. taxonomy of live beings, and also cyclic, net-like, and chain-like domains.

This paper documents a literature review about most frequently used kinds of CM-based tasks and criteria that can be used to score these tasks. The rest of the paper is organized as follows. In the next section types of CM-based tasks are described. The third section describes three classes of the most frequently used criteria for scoring these tasks. The paper ends with conclusions.

2 Concept map-based tasks

Different kinds of CM-based tasks serve different purposes. In (Ruiz-Primo, Schultz & Shavelson, 2001) it is said that high-directed tasks impose different cognitive demands on students than low-directed tasks. High-directed tasks where a student has little freedom to express his/her knowledge structure are more likely to misinterpret the student's knowledge structure. High-directed tasks are useful for activating the student's knowledge, while low-directed ones enable students to represent their knowledge structure more precisely (Gouli, Gogoulou & Grigoriadou, 2003). At the same time, low-directed tasks demand more content knowledge (Ruiz-Primo,M.A et al., 2001); thus, these tasks may appear too challenging for students with less competency. There is no one most appropriate task for all assessment purposes, as there is no best scoring method that would be appropriate for all kinds of CM-based tasks and would reflect all aspects of knowledge structure.

Range of CM-based tasks is wide. In (Shavelson, Lang & Lewin, 1994) it is stated that there is no less than 128 diverse types of tasks. Even wider set – 739 tasks – can be found by varying these factors: there can be given complete (C), or partial (P) CM structure, or it can be not given at all (E), complete (C), partial (P) or empty (E) sets of concepts and linking phrases in the list or in the CM structure and there can also be included distractors – misleading concepts and linking phrases. Some of these factors are mutually dependent (see Fig.1). For example, if all concepts are given in the list, then there can be no concepts in the structure.

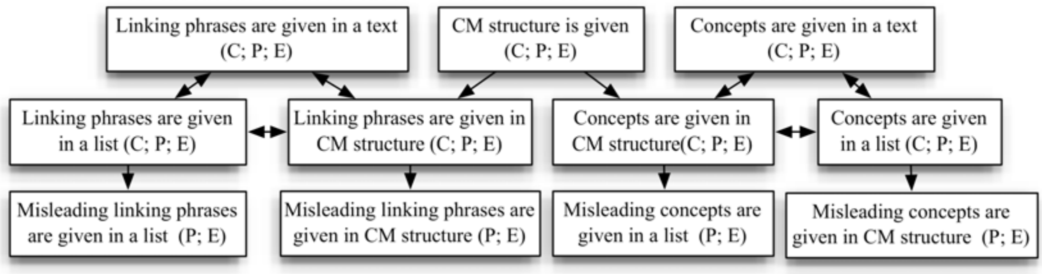

Figure 1. Factors that comprise a CM-based task and their interdependence

	Factors	**Task (source)**
1	(C; C; C; E; C; E; C)	**Fill-in-the-lines** (Ruiz-Primo et al., 2001; Shavelson, Ruiz-Primo & Wiley, 2005). **Relationships list completion** (Gouli, et al., 2004).
2	(C; C; E; C; C; C; E)	**Fill-in-the-Nodes** (Ruiz-Primo et al., 2001; Shavelson, Ruiz-Primo& Wiley, 2005); **Concept list completion** (Gouli, et al., 2004); **CM task** (Anohina-Naumeca, Grundspenkis, Strautmane, 2011).
3	(C; C; E; C; C; P; P)	**Select-and-fill-in** (Schau, 1999; Schau, 1997); **CM task** (Anohina-Naumeca, Grundspenkis, Strautmane, 2011).
4	(E; C+D; C+D; E; C+D; C+D; E)	**CM Task** (Taricani & Clariana, 2006; Koul, Clariana & Salehi, 2005; Hsu & Hsieh, 2005).
5	(E; C; C; E; C; C; E)	**S mapping technique** (Yin et al., 2005; Schaal, Bogner& Girwidz, 2010); **Concept-relationship lists construction** (Gouli, et al., 2004), **Construct-by-self** (Chang, Sung & Chen, 2001) **CM Task** (Herl, Baker & Niemi, 1996; Chang et al., 2005; Schaal, 2008; da Rocha, da Costa & Favero, 2008; Klein et al., 2002; Schacter et al., 1997; Fatemeh, Ahmad & Mohammad, 2011; O'Neil, Chuang & Chung, 2004; Sims-Knight et al., 2004; Anderson & Huang, 1989; Osmundson et al., 1999; Hoeft et al., 2003; Anohina-Naumeca, Grundspenkis, Strautmane, 2011).
6	(E; E; E; E; C; C; E)	**Construct-a-map with a list of concepts provided** (Plummer, 2008); **C mapping technique** (Yin et al., 2005); **Construct-a-map from scratch** (Ruiz-Primo et al., 2001; Shavelson, Ruiz-Primo, Wiley, 2005). **Concept-list construction** (Gouli, Gogoulou & Grigoriadou, 2003; Gouli, et al., 2004), **Pre-selected term maps** (Oliver, 2008); **CM task** (Schreiber & Abbeg, 1991; Rice, Ryan & Samson, 1998; Mls, 2006; Asan, 2007; Cathcart et al., 2010; McClure, Sonak & Suen, 1999; McPhan, 2008; Bolte, 1997; Nakiboglu & Ertem, 2010; Gerstner & Bogner, 2009; Roberts & Moriarty, 1996; Kankkunen, 2001; Luckie, Harrison & Ebert-May, 2011; Ruiz-Primo, Shavelson & Schultz, 1997; Lapp, Nyman & Berry, 2010; Markow & Lonning, 1998; Austin & Shore, 1995; Erduran-Avci, Unlu & Yagbasan, 2009; Adamczyk & Willson, 1996; Barenholz & Tamir, 1992; Luckie, Harrison & Ebert-May, 2004; Anohina-Naumeca, Grundspenkis, Strautmane, 2011);.
7	(E; E; E; E; E; E; E)	**Construct-a-map from scratch** (Ingec, 2009); **Free-construction task** (Gouli, Gogoulou & Grigoriadou, 2003; Gouli, et al., 2004), **Open-ended maps** (Oliver, 2008). **Map-generation task** (Hauser, Nückles & Renkl, 2006); **"Free range" CM task** (McLay & Brown, 2003); **CM Task** (Pearsall, Skipper, & Mintzes, 1997; West et al., 2002; Çakmak, 2010; Ozdemir, 2005; Gregoriades, Pampaka, & Michail, 2009; Kankkunen, 2001; Walker & King, 2002; Freeman & Urbaczewski, 2002; Stoddart et al., 2000; Borda et al., 2009; Turns, Atman & Adams, 2000; Beatty, 2000; West et al., 2002; Blackwell, & Williams, 2007; Fatemeh, Ahmad& Mohammad, 2011; Lavigne, 2005; Besterfield-Sacre, et al., 2004; Sanders et al., 2008; BouJaoude & Attieh, 2003; McKeown, 2009.

Table 1: Most frequently used types of concept map-based tasks

However, in reality a lot less variety of tasks is used. Reviewing literature, 23 types of tasks were found; here only seven more frequently used ones are mentioned (see Table 1). The first three of them are fill-in-the-map tasks, while remaining four are construct-a-map tasks. For this survey only those papers were selected that describe evaluation criteria used for scoring CM and where student fills or generates CM himself/herself instead of deriving the CM from student's response in some other form (e.g. text or concept relatedness assessments).

In the table factors that comprise a task are represented in such form: (<Structure>; <Relations given>; <Relations in the list>, <Relations in the structure>, <Concepts given>, <Concepts in the list>, <Concepts in the structure>). The first factor can have one of three values: "C" – complete; "P" – partial or "E" – empty. Other six factors can have three mentioned values and also "C+D" – complete, contains distractors. The table also contains different names that researchers have used to denote these tasks; sometimes the same name is used for different tasks (e.g. construct-a-map from scratch).

As can be seen from the table, construct-a-map tasks are used more frequently than fill-in-the-map tasks. Around 85% of summarized reports document the usage of a construct-a-map task alone or it's comparison to one or several different tasks. It is due to their ability to elicit more information about student's knowledge structure, which is also one of the main reasons for interest in using CMs as a knowledge assessment tool.

3 Concept map assessment criteria

An assessment is a combination of a task, response format and scoring system (Ruiz-Primo, & Shavelson, 1996). Scoring system in CM-based assessment usually employs a combination of several criteria because different criteria measure different aspects of knowledge represented by a CM (e.g. number of propositions reflect the volume of the knowledge, number of hierarchy levels – the depth of knowledge, etc.) There is a plethora of criteria used to assess CM-based tasks. It is possible to measure various aspects of a CM as well as its creation process (Yin et al., 2005). The choice of criteria depends on the aim of assessment – if it is an additional or the only technique used for evaluation of knowledge. The choice depends also on the characteristics of a domain where knowledge is to be measured and mode of assessment (manual or automated).

In the following subsections criteria that are used for certain kinds of CM-based tasks and their level of automation are described. Criteria are divided in three groups: (a) criteria that measure CM components, such as number of concepts, levels of hierarchy etc., (b) criteria that describe the structure as a whole such as correspondence to certain patterns, diameter of the graph etc., (c) other criteria. Tables in subsections 3.1, 3.2, and 3.3 contain references only to some of the sources where usage of a certain criteria is mentioned.

3.1 CM component measures

CM component measures include criteria that measure the quantity and quality of distinct elements of CM (see table 2). These include criteria of one of the most frequently used assessment schemes, proposed by Novak and Gowin (Novak & Gowin, 1984) – number of propositions, hierarchy levels, examples and cross links. The mode of assessment used in each source is denoted by the letter A (automated), M (manual), SA (semi automated) or U (not mentioned).

Criteria	Example of usage	Task
Number of concepts	Schaal, 2008[A]; Kankkunen, 2001[M]; Oliver, 2008[M]	5; 6; 7
Completeness of concepts used	Gouli et al., 2004[A]; Gouli, Gogoulou & Grigoriadou, 2003[A]; Rice, Ryan & Samson, 1998[M]; Koul, Clariana & Salehi, 2005[M]	1; 2; 4; 5; 6; 7
Quality of concept labels	Çakmak, 2010[M]; Stoddart et al., 2000[M]	7
Number or propositions	Schreiber & Abbeg, 1991[M]; Nakiboglu & Ertem, 2010[M]; Borda et al., 2009[M]; Koul, Clariana & Salehi, 2005[A]	4; 5; 6; 7
Completeness of relationships	Gouli et al., 2004[A]; Gouli, Gogoulou & Grigoriadou, 2003[A]; Walker & King, 2002[U] Koul, Clariana & Salehi, 2005[M]	1; 2; 4; 5; 6; 7
Proposition correctness**	Anohina-Naumeca, Grundspenkis & Strautmane, 2011[A]; da Rocha, da Costa & Favero, 2008[A]	2; 3; 5; 6
Proposition correctness*	Schaal, 2008[A]Gouli et al., 2004[A]; Fatemeh, Ahmad & Mohammad, 2011[A]; McClure, Sonak & Suen, 1999[M]; Luckie, Harrison & Ebert-May, 2011[A]; Taricani & Clariana, 2006[SA];	1; 2; 4; 5; 6; 7
Proposition quality (correctness, validity)	Yin et al., 2005[M]; Ruiz-Primo et al., 2001[M]; Ruiz-Primo, Shavelson & Schultz, 1997[M]; West et al., 2002[M]; Stoddart et al., 2000[A]	1; 2; 5; 6; 7
Proposition's depth of	Stoddart et al., 2000[M]	7

explanation		
Correct propositions that are not present in expert's CM	Anohina-Naumeca, Grundspenkis & Strautmane, 2011[M]; da Rocha, da Costa & Favero, 2008[A]; Cathcart et al., 2010[M]	2; 3; 5; 6
Proposition similarity to expert's CM	Osmundson et al., 1999[A]; Oliver, 2008[M]	5
Proposition correspondence to a category of relations	Herl, Baker & Niemi, 1996[M]; Schacter et al., 1997[A]	5
Proposition relevance	Klein et al., 2002[A]; Kankkunen, 2001[M]	5; 6
Correct places of concepts and relations	Chang, Sung & Chen, 2001[A]; Schau, 1999[M]	3; 5
Number of levels of hierarchy	Luckie, Harrison & Ebert-May, 2004[A]; Gouli, Gogoulou & Grigoriadou, 2003[A]; Hsu & Hsieh, 2005[M]	4; 6; 7
Concepts per level	Beatty, 2000[M]	7
Quality of hierarchy	Roberts & Moriarty, 1996[M]; Turns, Atma & Adams, 2000[M]	6; 7
Frequency of branching	Pearsall, Skipper & Mintzes, 1997[M]; Borda et al., 2009[M]	7
Number of cross-links	Osmundson et al., 1999[A]; Luckie, Harrison & Ebert-May, 2004[A]; Gouli, Gogoulou & Grigoriadou, 2003[A]; Hsu & Hsieh, 2005[M]	4; 5; 6; 7
Number of strands (major themes)	Schreiber & Abbeg, 1991[M]; Oliver, 2008[M]	6; 7
Number of examples	Nakiboglu & Ertem, 2010[M]Kankkunen, 2001[M]; Hsu & Hsieh, 2005[M]	4; 6; 7

* In comparison to expert's CM

** In comparison to expert's CM and its derivations

Table 2: CM scoring criteria that measure CM components

As can be seen from the last column in this table, fill-in-the-map tasks are mostly assessed by the number of concepts and relationships and the quality of propositions they comprise. It is meaningful to assess such criteria as levels of hierarchy, number of strands and cross-links and examples only for construct-a-map tasks because they actually describe the quality of a student's created structure. There are also two criteria that are meaningful only for tasks where the student generates concept labels and linking phrases by himself/herself, namely, the quality of concept labels and the proposition's depth of explanation. The assessment of propositions correctness criterion in various sources is related to all or a subset of such proposition components as linking phrase, direction of the arc, propositions weight (importance) and concepts linked. Some authors use only two levels of correctness while others consider also partially correct propositions. About 40% of sources report automated assessment of criteria that belong to this group. However there are some currently manually assessed criteria that could be easily automated (e.g. concepts per level and frequency of branching).

Criteria	Example of usage	Task
Convergence with expert's CM	Ruiz-Primo et al., 2001[M]; Ruiz-Primo, Shavelson & Schultz, 1997[M]; BouJaoude & Attieh, 2003[M]	1; 2; 6; 7
Salience	Ruiz-Primo et al., 2001[M]; Ruiz-Primo, Shavelson & Schultz, 1997[M]; BouJaoude & Attieh, 2003[M]	1; 2; 6; 7
Goldsmith's closeness index	Chang et al., 2005[A]	5
Similarity to experts' CM	Chang et al., 2005[A]; Schaal, 2008[A]; McKeown, 2009[A]	5; 7
Diameter of a graph	Sanders et al., 2008[U]	7
Maximum degree of concept	Sanders et al., 2008[U]	7
Spanning tree of the map	McKeown, 2009[A]	7
Number of hierarchical segments	Besterfield-Sacre et al., 2004[M]	7
Ruggedness (unconnected parts)	Schaal, 2008[A]; Koul, Clariana & Salehi, 2005[A]; Austin & Shore, 1995[M]	5; 6
Spatial distance	Mls, 2006[M]; Taricani & Clariana, 2006[A]	4; 6
Graph connectivity	Austin & Shore, 1995[M]	6
Correspondence to structural patterns	Yin et al., 2005[M]; Nakiboglu & Ertem, 2010[M]; BouJaoude & Attieh, 2003[M]; Koul, Clariana & Salehi, 2005[M];	4; 5; 6; 7
Hierarchiness	Ruiz-Primo, Shavelson & Schultz, 1997[M]	6
Domain-specific subpatterns	Sims-Knight et al., 2004[M]	5
Richness of relationships	Lapp, Nyman & Berry, 2010[M]; McKeown, 2009[A]	6; 7
Holistic score of overall quality	Luckie, Harrison & Ebert-May, 2011[M]; Gregoriades, Pampaka & Michail, 2009[M]; Besterfield-Sacre et al., 2004[M]	6; 7

Table 3: CM scoring criteria that measure CM structure parameters

3.2 CM structure measures

Criteria of this group are most frequently used for construct-a-map tasks because it is meaningful to measure various aspects of a structure only then when the student has created this structure. The first four criteria are evaluated by comparing the student's CM to the expert's CM, but others measure graph characteristics.

This class of criteria mostly strives to evaluate the interconnectedness of the student's CM, because as a result of learning knowledge structure becomes more and more interconnected (Ruiz-Primo, & Shavelson, 1996). The expert's generated CMs are characterized by a small number of concepts compared to a number of relationships between them (Novak, & Cañas, 2006). Correspondence to structural patterns also aims at assessing the complexity of a structure by comparing students' created constructs to linear, spoke-like, tree-like, net-like and other patterns.

Only about one third of sources report automated assessment of criteria of this group, because when used for construct-a-map tasks where linking phrases must be generated by the student (tasks 6 and 7) part of them involves analysing semantics of the relationships (e.g. salience and convergence with expert's CM). Correspondence to the various subpatterns is one of the most widely used criteria of this group because it reveals an important characteristic of a knowledge structure as different patterns correspond to different levels of understanding. Still it is complicated to evaluate it automatically because student's CM can contain structures that are inexact matches to the structural patterns.

3.3 Other CM measures

Aside from the scoring CM elements and structure, the process of completing the task can also be measured by inspecting the student's actions log or amount of help used. In computer-based knowledge assessment systems, such as IKAS (Anohina-Naumeca, Grundspenkis & Strautmane, 2011) data, for evaluation of these criteria can be easily gathered automatically. The advancement of computing technologies also allows including more information in a CM such as notes, Web links, digital library resources and images (Oliver, 2008). This additional information also characterizes the student's understanding about the topic, so appropriate evaluation criteria must be included in the scoring system.

Criteria	Example of usage	Task
Amount of help used	Anohina-Naumeca, Grundspenkis & Strautmane, 2011[A]	2; 3; 5; 6
Relevance of attached web document	Schacter et al., 1997[SA]; Oliver, 2008[M]	5; 7
Students actions log	Schacter et al., 1997[SA]	5
Errors, missing elements, used distractors	Gouli et al., 2004[A]; Kankkunen, 2001[M]; Luckie, Harrison & Ebert-May, 2011[A]; Rice, Ryan & Samson, 1998[M]	1; 2; 5; 6; 7
Temporal proximity of creating propositions	Lapp, Nyman & Berry, 2010[M]	6

Table 4: Other CM scoring criteria

4 Conclusions

Although there exist so many variations of CM-based tasks, an CM-based knowledge assessment system does not need to include them all to be useful in various stages of the learning process. It is sufficient if it has a few high-directed tasks for assessment in early stages of learning and some of the low-directed ones for elicitation of deep understanding.

Current computing technologies allow including more criteria in the scoring system without burdening the teacher with a complex computations. Thus an automated CM-based knowledge assessment system has a potential for regular knowledge assessment even for large groups of students. There is still a need for an CM-based knowledge assessment system that could perform the assessment automatically with a little intervention by the teacher. It is crucial for those tasks where student generates linking phrases and/or concept labels because the student can use different words to express correct knowledge than the teacher does. Currently analysis of propositions in such tasks usually is performed manually although there are some attempts to automate it.

As scoring CM components and scoring CM structure reveals different aspects of a knowledge structure, a comprehensive scoring mechanism should use a combination of criteria belonging to both of these groups. Especially in cases where the score of the CM is used as a measure of learning success.

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