Evaluating Learner's Knowledge Level on Concept Mapping Tasks

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Abstract

In this paper, we propose a scheme for evaluating learners' knowledge level on concept mapping tasks. The assessment process focuses on the propositions presented on learner's map as well as on the missing ones with respect to the propositions presented on expert map. The evaluation of learner's knowledge level depends on the weights assigned to the concepts and propositions on expert map as well as to specific categories of errors that may be identified on learner map. The proposed scheme has been embedded in COMPASS, an adaptive web-based concept map assessment tool. An application example of the evaluation of learner's knowledge level and the performance feedback provided are presented.

1. Introduction

Concept maps are considered to be a valuable tool of an assessment toolbox, as they provide an explicit and overt representation of learners' knowledge structure and promote meaningful learning [7]. A concept map is comprised of nodes, which represent *concepts*, and links, annotated with labels, which represent *relationships* between concepts, organized in a structure (hierarchical or non-hierarchical) to reflect the central concept of the map. The triple Concept-Relationship-Concept constitutes a *proposition*, which is the fundamental unit of the map. A map may also include cross-links, which are relationships between concepts in different regions/ domains within the map, and examples clarifying the meaning of a given concept.

Concept maps have been extensively used, especially in science education, to assess learners' knowledge structure, in large-scale as well as in classroom assessment. The assessment is usually accomplished by comparing learner's map with the expert's one [8]. Two most commonly investigated assessment methods are the structural method and the relational method. The structural method [7] is limited to hierarchical maps and takes into account only the valid map components (e.g. propositions, examples, links/cross-links). The relational method focuses on the accuracy of each proposition, presents a high degree of inter-rater reliability and the evaluation results correlate well with both classroom and standardized tests [8], [6].

Most of the assessment schemes proposed in literature either have been applied to studies where the assessment of concept maps is human-based [8], [6], or constitute a theoretical framework [5]. Regarding the computer-based assessment of concept maps, it seems that it is in its infancy as the number of systems that have embedded a scheme for automated assessment and for feedback provision is minimal. In the system proposed by Chang et al. [1], the structural method is followed for specific assessment tasks and the scoring criteria include the number of valid propositions, valid hierarchical levels and valid cross-links. Conlon [2] adopts a relational method in his Reasonable Fallible Analyzer, taking into account (i) the characterization of a proposition: fully correct (corresponds exactly to a proposition on expert map) or partly correct (the relationship between two concepts or the direction of the arrow is incorrect), (ii) the weights of each characterization, and (iii) the number of valid concepts included in learner's map. The first system takes into account only the valid components, ignoring the invalid ones, which may contribute to the overall knowledge structure, whilst the assessment, in the second system, is based on the identification of quite a few errors. It seems that the development of a comprehensive scheme to support computer-based assessment of concept maps is still an open issue.

Our work is an extension of this line of research. We propose a scheme for the assessment of concept

maps and subsequently for the evaluation of learner's knowledge level on the central concept of the map. The proposed scheme adopts the relational method by examining the accuracy and completeness of the presented propositions on learners' map and taking into account the missing ones, with respect to the propositions presented on the expert map. The assessment scheme has been embedded in COMPASS (COncept MaP ASSessment tool), an adaptive web-based concept map assessment tool.

The rest of the paper is structured as follows: In Section 2, a brief overview of COMPASS tool is provided, while in Section 3, the proposed scheme is presented. In Section 4, an application example illustrating the evaluation of learner's knowledge level and the performance feedback provided is presented. The paper ends, in Section 6, with the main points of our work.

2. An Overview of COMPASS

COMPASS aims to assess the learners' understanding as well as to support the learning process [3]. In particular, COMPASS serves (i) the assessment process by employing a variety of activities in order to assess learner's knowledge, and (ii) the learning process by providing different informative, tutoring and reflective feedback components, tailored to learners' individual characteristics and needs [4].

Based on an assessment goal that learner selects, which corresponds to a fundamental topic of the subject matter, COMPASS provides various activities, addressing specific learning outcomes. Depending on the outcomes, the activities may employ different concept mapping tasks, which are characterized along a directedness continuum from high-directed to low-directed, based on the information/support provided to learners. More specifically, COMPASS supports the *construction of a map* as well as the *evaluation* (i.e. the evaluation/correction of a map in case of any errors identified), the *extension* (i.e. add new concepts and

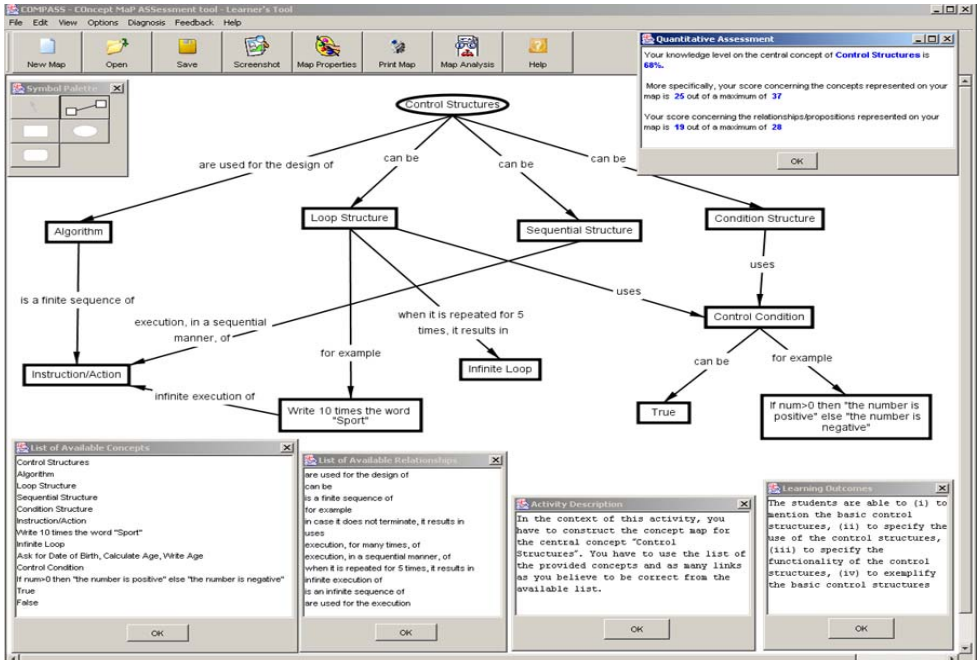

Figure 1. The main screen of COMPASS. A concept map of a learner, in the context of a "concept-relationship list construction" task, is presented on the Working Area. The four windows at the bottom correspond to the (i) provided list of concepts, (ii) provided list of relationships, (iii) description of the activity, and (iv) learning outcomes addressed by the activity, while the window at the upper right corner correspond to the quantitative assessment of the map. A number of errors are identified (see Table 1) such as (i) CDP: the position of the concept "If num>0 then the number is positive else the number is negative" is incorrect; thus, a SR error and a MR error are identified, (ii) MCR: the concept "Ask for Date of Birth, Calculate Age, Write Age" is missing, (iii) SR: the relationship between the concepts "Infinite Loop" and "Write 10 times the word Sport" is superfluous, (iv) INR: the relationship between the concepts "Loop Structure" and "Infinite Loop" is incorrect, (v) MR: a relationship between the concepts "Loop Structure" and "Instruction/Action" is missing, (vi) MCGR: the concept "False" is missing; thus the concept of "Control Condition" is not related to all the required concepts.

relationships) and the *completion* (i.e. filling the missing components) *of a given map*. Also, combinations of the abovementioned tasks are supported. Depending on the degree of support provided, learners may have at their disposal a list of concepts and/or a list of relationships to use in the task (e.g. "concept list construction" task, "concept-relationship list extension" task) or may be free to choose the desired concepts and/or relationships (e.g. "free construction" task). The provided lists may contain not only the required concepts/relationships but also concepts/relationships that play the role of distracters (i.e. concepts that can be characterized as superfluous and relationships that are incorrect).

In Figure 1, the main screen of COMPASS is shown. It consists of (i) the menu and toolbar, which provide direct access to several facilities such as the provision of feedback and the analysis of the map, and (ii) the Working Area. The learner may check/verify his/her map by activating the button "Map Analysis" from the toolbar or the "Diagnosis" menu (see Figure 1; fifth selection on the menu), which includes the options: (i) "Map Analysis" that analyzes learner's map in order to identify any errors, (ii) "Qualitative Assessment" that diagnoses learner's incomplete understanding/beliefs and false beliefs, (iii) "Quantitative Assessment" that evaluates learner's knowledge level as well as provides specific performance feedback (see Figure 1). Moreover, through the "Feedback" menu, the following options are available: (i) "Visual Feedback" that graphically annotates the errors, if any, identified on the map, and (ii) "Interactive Feedback" that provides personalized feedback for each one of the errors [4], through a dialogue framework between the learner and the tool. The paper focuses on the quantitative assessment.

3. Evaluation of Learner's Knowledge Level

The quantitative assessment of learners' concept maps aims to evaluate learner's knowledge level on the central concept of the map, which is further exploited as one of the sources of adaptation for the provision of personalized feedback. It is based on the map analysis, which identifies specific error categories, and on the weights assigned to each error category (Table 1) as well as to each concept (WCe_i) and proposition (WPe_i) that appear on expert map. The weights are assigned by the teacher and reflect the degree of importance of the concepts and propositions as well as of the error categories, with respect to the learning outcomes addressed by the activity. This way, the teacher has the possibility to personalize the assessment process. For example, in case the teacher wishes to assess learners' ability to relate different regions of the map, s/he may set higher weights to propositions that are cross-links and low/zero weights to error categories (e.g. "MCR") that are not considered critical to be measured into the total score.

During the assessment process, the presented components of the propositions (i.e. the included concepts and their corresponding relationship(s)) on learners' map are examined and the missing ones are taken into account. More specifically, the assessment process consists of the following steps:

(i) at first, the weights of the concepts (WCi), that exist in both maps (learner's and expert) and they are at the correct position, are added to the total learner's score, denoting that the learner knows the specific concepts. Also, the weights of the propositions on learner's map (WPi), which correspond exactly to propositions on the expert map, are added to the total score, denoting that the learner knows the specific propositions (see Formula 1),

(ii) for all the propositions/concepts, which are presented on learner's map and are partially correct (i.e. the errors "IR", "IC", "INR", "CDP", and "DAD" are identified), their weights are partially added to the total score; their weights are adjusted according to the weights of the corresponding error categories and added to the total score (W_{EC}: Weight for Existing Components) (see Formulas 1 and 2),

(iii) for all the propositions/concepts, which are superfluous or missing from the learner's map (i.e. the errors "SCR", "SR", "MR", "MCR", and "MCGR" are identified), their weights are ignored and the weights of specific concepts (see Formula 3), which have been fully added to the score at the first step, are adjusted according to the weights of the corresponding error categories and subtracted from the total score (W_{NESC}: Weight for Non Existing or Superfluous Components) (see Formulas 1 and 3),

(iv) the total learner's score is divided by the expert's score (weights of all the concepts (WCe_i) and propositions (WPe_i), presented on expert map, are added) to produce a ratio as a similarity index (see Formula 1) ($S \in [0,1]$).

It has to be mentioned that for those propositions, which are characterized as missing, the weights of the involved concepts and the weights of the propositions

Table 1. The error categories that may be identified on learner's map and their corresponding weights

Categories of Errors and their Description	Weights	
	Symbol	Denotes the degree that …….
Incomplete Relationship (IR): the set of the relationships between two concepts is incomplete, as several relationships are missing, i.e. concepts Ci and Cj are related with m relationships on expert map, while on learner's map n relationships appear, where n<m.	W_{IR}	the weight of the specific propositions are taken into account.
Missing Relationship (MR): the relationship between two concepts Ci and Cj that should be related is missing.	W_{MR}	the weights of the specific concepts Ci and Cj should not be taken into account, as the learner does not know how to relate them.
Missing Concept and its Relationships (MCR): a concept Cj related with the concept Ci on expert map is missing from learner's map, resulting also into missing relationship(s).	W_{MCR}	the weight of the concept Ci should not be taken into account as the corresponding relationship(s), with the missing concept, are also missing.
Missing Concept belonging to a Group and its Relationships (MCGR): the set of the relationships between one concept Ci and a group of concepts is incomplete because at least one of the concepts belonging to the specific group is missing.	W_{MCGR}	the weight of the specific concept Ci should not be taken into account as an expected proposition is missing due to the missing concept.
Incorrect Concept (IC): a concept is related to an incorrect concept, which should be replaced with another concept.	W_{IC}	the weight of the specific proposition is taken into account, as one of the concepts is incorrect.
INcorrect Relationship (INR): two concepts are related with an incorrect relationship, which should be substituted.	W_{INR}	the weight of the specific proposition is taken into account, as the corresponding relationship is incorrect.
Concept at Different Place (CDP): a concept Ci is at an incorrect position.	W_{CDP}	the weight of the specific concept Ci is taken into account.
Difference in Arrow's Direction (DAD): two concepts are related with a correct relationship, but the direction of the arrow on the linking line is incorrect.	W_{DAD}	the weight of the specific proposition is taken into account.
Superfluous Concept and its Relationships (SCR): a superfluous concept appears which should be deleted.	W_{SCR}	the weight of the concept, which is related with the superfluous concept, should not be taken into account.
Superfluous Relationship (SR): two concepts Ci and Cj are related although they should not.	W_{SR}	the weights of the concepts Ci and Cj should not be taken into account as learners relates these concepts although they should not be related.
Missing Proposition (MP): the proposition is missing as the two concepts involved in the proposition and their relationship(s) do not appear on the learner's map.	No weight is supported, as the corresponding weights of the concepts and the proposition are not added to the total learner's score.	

are ignored for the computation of the total learner's score. All the abovementioned for scoring learners' maps are formalized as the following:

$$S = \frac{\sum_{\substack{\text{for all i where Ci exists in expert's map and Ci is at the correct position}}} WC_i + \sum_{\text{for all i where } P_i = Pe_i} WP_i + W_{EC} - W_{NESC}}{\sum_{\text{for all i}} WCe_i + \sum_{\text{for all i}} WPe_i} \quad (1)$$

$$W_{EC} = \sum_{\substack{\text{for all the propositions that the specific errors are identified}}} WC_i * W_{CDP} + WP_k * W_{INR} + WP_l * W_{DAD} + WP_m * W_{IR} + WP_n * W_{IC} \quad (2)$$

Where, WC_i: the weight of the concept, which is at an incorrect position, WP_k: the weight of the proposition in which the relationship is identified as incorrect, WP_l: the weight of the proposition, where the direction of the arrow is incorrect, WP_m: the weight of the proposition, in which the relationship is identified as incomplete, WP_n: the weight of the proposition, in which an incorrect concept is included, W_{CDP}, W_{INR}, W_{DAD}, W_{IR}, W_{IC} the weights of the corresponding error categories (see Table 1).

$$W_{NESC} = \sum_{\substack{\text{for all the propositions that the specific errors are identified}}} (WC_b + WC_j) * W_{MR} + WC_k * W_{SCR} + (WC_l + WC_m) * W_{SR} + WC_n * W_{MCGR} + \sum_{\substack{\text{for all i that the missing concept is related to}}} WCi * W_{MCR} \quad (3)$$

Where, WC_b and WCj: the weights of the concepts that are not related although they should, WC_k: the weight of the concept that a superfluous concept is related to, WC_l and WC_m: the weights of the concepts that are related although they should not, WC_n: the weight of the concept, which is not related to the expected group of concepts as a concept belonging to that group is missing, WC_i: the weight of the concept that a missing concept is related to, W_{MR}, W_{SCR}, W_{SR}, W_{MCGR}, W_{MCR} the weights of the corresponding error categories (see Table 1).

4. An Application Example

In the context of a preliminary evaluation of the proposed assessment scheme, sixteen concept maps were constructed by high-school students and evaluated by COMPASS. A student's concept map is presented in Figure 1. For the assessment of the maps, an expert map was constructed (see Figure 2) and specific weights were assigned to the concepts and propositions. For the different error categories, the following weights were assigned, reflecting that the accuracy of the existing propositions is considered more significant than the missing ones: 0.2 for "IR", 0.4 for "IC" and "INR", 0.5 for "CDP", 0.7 for "DAD", 0.3 for "SCR" and "SR", 0.1 for "MR", "MCR" and "MCGR".

Using the formulas (1), (2), (3) and the abovementioned weights, the similarity index S of the student's concept map to the expert map was calculated, as 0.68. Thus, COMPASS assigned the value of 6.8 to the student's knowledge level. It is important to mention that the teacher of the specific student assigned the score of 7 to the map, on a scale from 1 to 10. The performance feedback provided informs the student about his/her knowledge level on the central concept

of the map as well as about his/her score concerning the concepts and the relationships/ propositions represented on his/her map (Figure 1). Moreover, the analysis of the map informs the student about the evaluation process (assessment criteria) as well as the errors identified (Figure 3).

Figure 2. The expert map and the weights assigned to the concepts and the propositions.

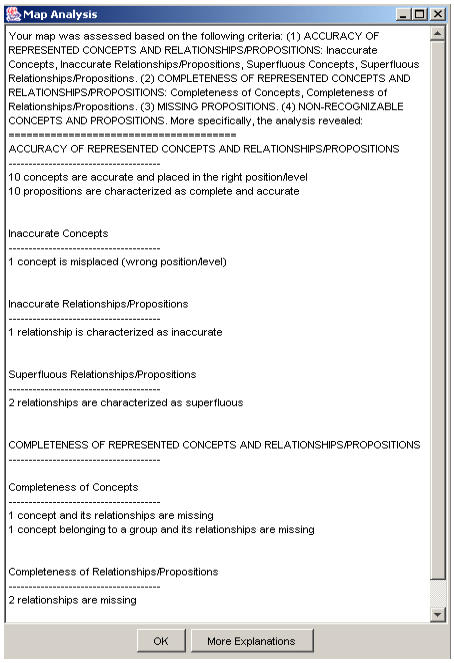

Figure 3. The analysis of the map presented in Figure 1. COMPASS provides more information about the errors identified through the button of "More Explanations".

5. Conclusions

In this paper, a scheme for the quantitative assessment of concept maps, and subsequently for the evaluation of learner's knowledge level on the central concept of a map, was presented. The scheme adopts the relational method and focuses on the assessment of both the presented propositions on learners' map (i.e. the included concepts and their corresponding relationship(s)) and the missing ones with respect to the propositions presented on expert map. The evaluation of learner's knowledge level depends on the weights assigned to the concepts and the propositions included in expert map as well as to the error categories. The proposed scheme has been embedded in COMPASS in order to evaluate learner's knowledge level on concept mapping tasks. The analysis of learner's map is accompanied by a brief explanation of the errors identified and the performance feedback informs the learner about his/her knowledge level on the central concept of the map as well as about his/her score concerning the concepts and the relationships/ propositions represented on his/her map.

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