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DIVERSITY OF CONCEPT MAPPING TASKS: DEGREE OF DIFFICULTY, DIRECTEDNESS, AND TASK CONSTRAINTS

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Abstract. Concept maps have been used for knowledge assessment already for several decades. At the same time no extensive overview has been made on possible concept mapping tasks and no formal methods have been developed for comparing the degree of difficulty of different assessment tasks based on concept maps. There are only some research studies on task characterization, task comparison, use of different tasks for assessing students with different knowledge level and extending task types considering constraints on sets of concepts and linking phrases. The paper examines diversity of concept mapping tasks from the perspective of possible task constraints which are considered in relation to the directedness continuum as a factor of the degree of task difficulty. The main contributions are the general view on diversity of concept mapping tasks and the detailed framework for identification of possible concept mapping tasks taking into account task constraints.

1 Introduction

Concept maps have well-established basis for their use in teaching, learning, and assessment processes. As an assessment instrument, they offer a wide range of tasks allowing elicitation of students' knowledge structures and their further examination with aim to identify and remediate knowledge gaps and misunderstandings. At the same time analysis of available information sources shows that no formal methods have been developed for comparing the degree of difficulty of different assessment tasks based on concept maps. There is only Ruiz-Primo's research about characterization of a concept map task assessment by a directedness continuum from high-directed to low-directed tasks depending on the information provided to students (Ruiz-Primo, 2004) and Yin's et al. study on comparison of two types of concept mapping tasks (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). In the work of Lukashenko and Anohina-Naumeca, a student receives concept mapping tasks with the different degree of task difficulty taking into account his/her previous assessment results (Lukashenko & Anohina-Naumeca, 2010). Grundspenkis (Grundspenkis, 2011) has paid attention to possible types of tasks considering constraints on sets of concepts and linking phrases available to students during completion of tasks.

The paper examines diversity of concept mapping tasks from the perspective of possible task constraints which are considered in relation to the directedness continuum as a factor of the degree of task difficulty. The main contributions are a general view on diversity of concept mapping tasks and a detailed framework for identification of possible concept mapping tasks taking into account task constraints. The paper is organized as follows. Section 2 gives an overview of the developed concept map based intelligent knowledge assessment system which triggered the research presented in this paper because of necessity to extend a set of tasks implemented in the system. Section 3 describes the identified diversity of concept mapping tasks in the context of knowledge assessment. Section 4 focuses on task constraints taking into account the directedness continuum. Acknowledgments, conclusions, and directions of future work are presented at the end of the paper.

2 Overview of IKAS

Since 2005, the concept map based ***i***ntelligent ***k***nowledge ***a***ssessment ***s***ystem called IKAS has been developed at Riga Technical University, Latvia (Anohina-Naumeca, Grundspenkis, & Strautmane, 2011; Grundspenkis, 2011; Lukashenko & Anohina-Naumeca, 2010). It has two main goals: 1) to support students in self-assessment process of their knowledge, and 2) to support teachers in improvement of study courses through systematic analysis of students' knowledge. Assessment process in IKAS is based on concept maps.

The system is used in the following way. The teacher divides a study course into several stages and builds a concept map for each of them in such a way, that a concept map of each stage is nothing else than an extension of the previous one. Therefore, the concept map of the last stage includes all concepts studied in the course and all relations among them. At the end of each stage the created concept maps in the form of concept mapping tasks are offered to students for knowledge self-assessment. After completion of a task, the system performs automatic comparison of concept maps of the students and the teacher and provides feedback.

At the moment six tasks are implemented in the system (Table 1): four of them provide the structure of a concept map and students must fill it using the offered set of concepts and/or linking phrases, and two tasks

assume construction of a concept map by students using the offered set of concepts and/or linking phrases. Ten transitions between the tasks are realised. Five of them increase the degree of task difficulty. They are carried out automatically if a student has reached the teacher's specified number of points in the current assessment stage without reducing the degree of task difficulty of the original task. Other five transitions reduce the degree of task difficulty after a voluntary request from the student during task solving. Teachers set the initial degree of task difficulty for their courses.

<table>
<tr><th>Degree of task difficulty</th><th>Task</th><th>Structure of a concept map</th><th>Concepts</th><th>Linking phrases</th></tr>
<tr><td>1st – the simplest</td><td rowspan="3">To fill in the structure of a concept map</td><td rowspan="3">Given</td><td>Part of concepts are already inserted into the structure, the other part is given as a list and must be inserted by students</td><td>Inserted into the structure</td></tr>
<tr><td>2nd</td><td rowspan="2">Given as a list and must be inserted by students</td><td rowspan="2">Not used</td></tr>
<tr><td>3rd</td></tr>
<tr><td>4th</td><td>Given as a list and must be inserted by students</td></tr>
<tr><td>5th</td><td rowspan="2">To construct a concept map</td><td rowspan="2">Must be created by students</td><td rowspan="2">Given as a list and must be related by students</td><td>Not used</td></tr>
<tr><td>6th – the most difficult</td><td>Given as a list and must be inserted by students</td></tr>
</table>

Table 1: Tasks Implemented in IKAS

During the period from 2005 till 2011, IKAS has been evaluated in 20 study courses. After use of the system, students are always offered to provide answers on a questionnaire eliciting their opinion about concept maps as a knowledge assessment method and functional capabilities of IKAS. So far 456 questionnaires have been processed. Regardless the fact that, in general, students evaluate positively their experience with IKAS, answers give evidence that the offered tasks are not suitable for all students (Table 2). First of all, there are students who do not like working with concept maps. Secondly, always there are students who do not want to use concept maps in future. Thirdly, the most part of students have difficulties in completing concept mapping tasks. These facts, by the opinion of the system's developers, call for necessity to extend the set of tasks implemented in IKAS in order to support diversity of students in terms of their knowledge level and way of construction of knowledge structures and to provide more objective assessment process.

Question	Answer	Number of students' answers (%)
Do you like to use concept maps as a knowledge assessment method?	Yes	317 (69,5%)
	Neutral	86 (18,9%)
	No	53 (11,6%)
Would you like to use such a knowledge assessment method in other courses?	Yes	182 (39,9%)
	Probably	205 (44,95%)
	No	69 (15,15%)
Was it difficult for you to complete concept mapping tasks?	Very difficult	44 (9,7%)
	Difficult	256 (56,1%)
	Easy	145 (31,8%)
	Very easy	11 (2,4%)

Table 2: Students' Answers on the Questionnaire

3 Diversity of Concept Mapping Tasks

Concept maps have been used in different assessment tasks. In general, tasks can be divided into two main groups:

- simple concept mapping tasks which apply concept maps as the main assessment instrument and do not use other types of tasks simultaneously;
- compound concept mapping tasks which include a simple concept mapping task only as a part of assessment, for example, a student writes an essay and gives its summary as a concept map, or gives an answer as a concept map which is followed by an individual interview about the content of the constructed concept map (Rojas, Sánchez, Barrios, Vergara, Torres, & Bravo, 2008), or vice versa, an interview is at first and then a concept map is constructed on the basis of the answers received (Wehry, Algina, Hunter, & Monroe-Ossi, 2008).

The diversity of the simple concept mapping tasks is determined by the fact that a task consists of a combination of three parts (Ruiz-Primo & Shavelson, 1996):

- task demands which correspond to a task statement or, in other words, specify what students need to do, for example, students need to fill-in the structure of a concept map, to compare two concept maps, to evaluate correctness of a concept map, to construct a concept map, etc.;
- task constraints which restrict students' activities, for example, they determine what kind of the topology should be provided, if students receive all concepts needed for task solving or only part of them, etc.;
- task content structures which are an intersection between the task statement and constraints and the structure of the problem domain, i.e., how the problem domain affects a task, for example, students need to draw a linear concept map representing sequence of processes.

Task demands determine the type of a task. Here, two main categories can be identified:

1) tasks directly related to externalization of students' knowledge structures (internal representation of knowledge), for example, construct a concept map for a particular topic or fill-in the missing concepts in the structure;
2) tasks where students manipulate provided concept maps or their elements. Examples of such tasks are evaluation of correctness of a concept map, evaluation of correctness of a proposition, concept sorting (Ruiz-Primo & Shavelson, 1996), comparison of concept maps, etc.

Further in this paper attention is paid only to the simple concept mapping tasks related to externalization of students' knowledge structures.

4 Task Constraints

The concept mapping tasks can be characterized with the directedness continuum, i.e., the degree of task difficulty is influenced by the fact how much students have been directed during task solving, more precisely, how much information about the concept map students receive (Ruiz-Primo, 2004). The higher is the degree of directedness, the simpler is the task. The degree of directedness is associated with the task constraints mentioned above.

In general, the task constraints emerge from possible constraints on the elements of a concept map as a graph and their characteristics. These elements are:

- the whole structure of a concept map which is characterized by:
  - its availability to students;
  - presence of arc direction;
  - presence of arc weights;
- nodes representing a set of concepts in a problem domain;
- arcs defining relations between concepts and characterized by a set of linking phrases specifying semantics of relations.

With regard to availability of the structure of a concept map, three possible values can be defined:

- a full structure. It corresponds to the so called "fill-in-the-map" tasks where students must operate with the already provided structure of a concept map taking into account constraints on other elements of the concept map;
- an absent structure. It corresponds to the so called "construct-the-map" tasks (opposite to the "fill-in-the-map" tasks) where the structure of a concept map is not provided and students must create it in the framework of constraints on other elements of the concept map;
- a partial structure. In this case a part of the structure is already given ("fill-in-the-map" task), but students must extend it by adding new nodes and arcs ("construct-the-map" task). This type of tasks can be called "adjust-the-map" tasks.

Figure 1 displays the degree of directedness in relation to the previously described constraints on availability of the structure of a concept map. As "adjust-the-map" tasks are a combination of "fill-in-the-map" and "construct-the-map" tasks, further in the paper attention is paid to the detailed analysis of the these two types of tasks.

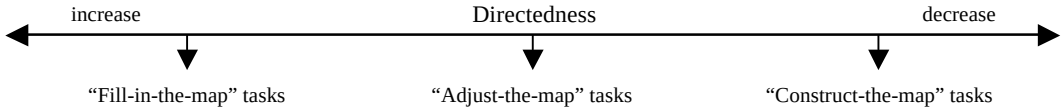

Figure 1. Task characterization with the degree of directedness.

Necessity to process arc directions increases the degree of task difficulty. Here, it is possible to define three main cases with some slight variations for “fill-in-the-map” and “construct-the-map” tasks:

- direction of arcs is not important in the context of the task and, therefore, the concept map is an undirected graph. It is suitable for tasks where linking phrases are not used and only the fact that concepts are related is important;
- direction of all arcs is important in the context of the task and, therefore, the concept map is a directed graph:
  - for “construct-the-map” tasks:
    - students constructing the concept map must provide direction for each arc;
  - for “fill-in-the-map” tasks:
    - direction of all arcs is provided in the structure of the concept map;
    - none of arcs are directed in the structure and students must provide direction of arcs;
    - a part of arcs in the structure are directed, for the other part students must provide direction;
- arcs are partly directed according to Novak when vertical arcs used for hierarchal relations are undirected and should be read from the bottom to the top and horizontal cross-links are directed (Novak, 1984):
  - for “construct-the-map” tasks:
    - students constructing the concept map must provide direction of arcs where it is necessary;
  - for “fill-in-the-map” tasks:
    - direction for arcs that need it is provided in the structure;
    - none of arcs are directed in the structure and students must provide direction of arcs that need it;
    - a part of arcs in the structure are directed, for the other part students must provide direction.

Figure 2 shows the degree of directedness taking into account constraints on direction of arcs in a concept map.

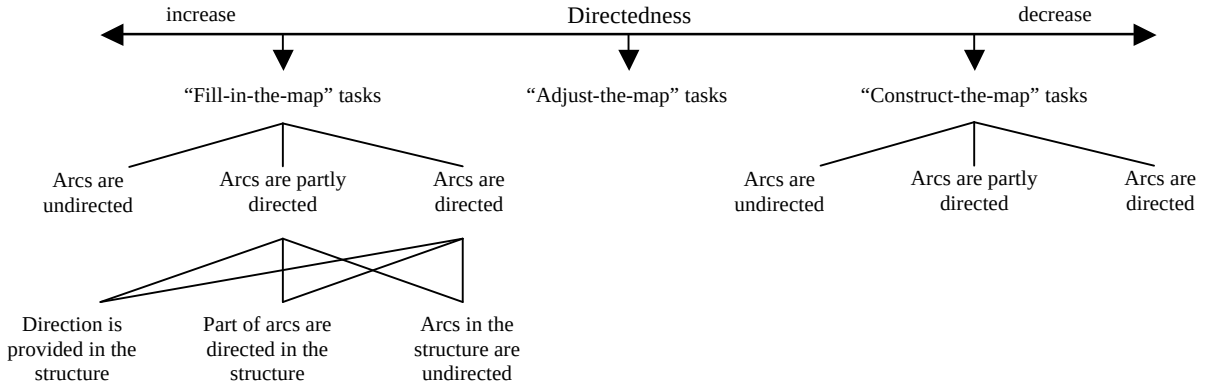

Figure 2. The degree of directedness in relation to constraints on arc direction.

According to Grundspenkis (Grundspenkis, 2011), concept maps are homogeneous graphs if all arcs in a concept map have the same weights or heterogeneous graphs if weights are different. In the former case, students must not care about determination of arc weights in “fill-in-the-map” or “construct-the-map” tasks. In the latter case, constructing a concept map students must provide weights of arcs. However, in “fill-in-the-map” tasks three different cases need to be considered (Figure 3):

- arc weights are provided in the structure of the concept map;
- arc weights are not provided in the structure and they must be determined by students;
- a part of arc weights are provided in the structure, the other part must be determined by students.

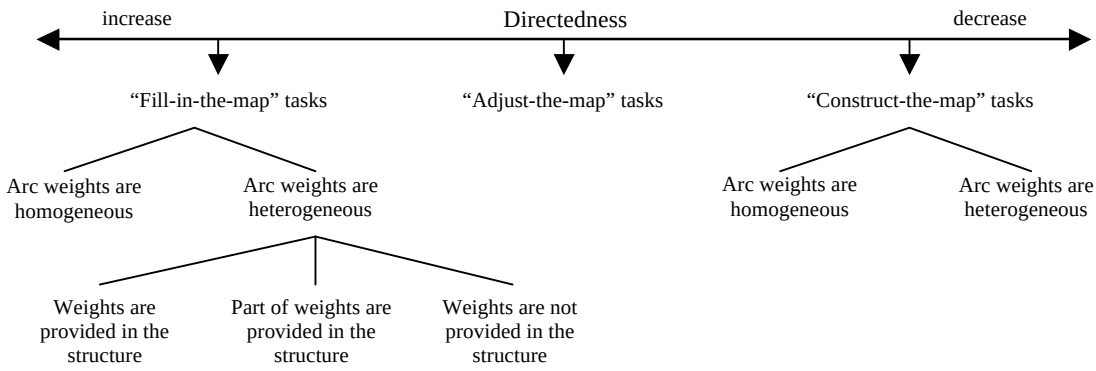

Figure 3. The degree of directedness in relation to constraints on arc weights.

A set of concepts is an integral part of any concept mapping task, because without it tasks do not have sense. However, linking phrases are optional as they only explain semantics of relations which presence is displayed by arcs. Therefore, considering constraints related to the sets of concepts and linking phrases (if linking phrases are used), it is necessary to take into account the previously specified constraints on the structure of a concept map. Then two different sets can be identified:

- the set of concepts/linking phrases already inserted in the structure of a concept map and serving as anchors/hints for completion of the task. There three values are possible:
  - an empty set. This case corresponds to “construct-the-map” tasks, because they do not offer the already provided structure of a concept map;
  - a full set. It is a case of “fill-in-the-map” tasks when all concepts or linking phrases are already inserted in the structure of a concept map;
  - a partial set. This case is also related to “fill-in-the-map” tasks when a part of concepts and/or linking phrases are already inserted in the structure of a concept map, but the other part must be filled in by students.

  Figure 4 shows the degree of directedness taking into account constraints on the set of concepts/linking phrases already inserted in the structure of a concept map.

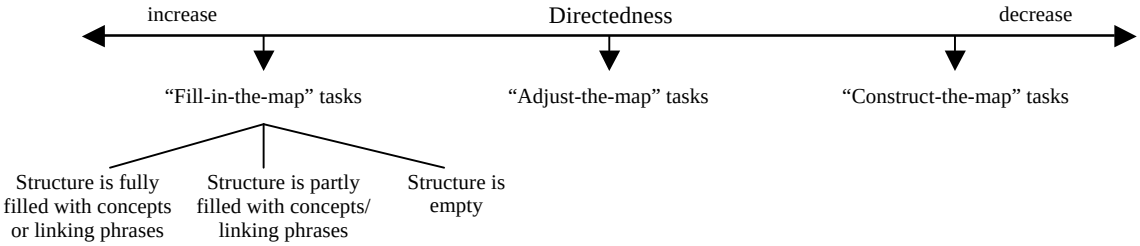

Figure 4. The degree of directedness taking into account constraints on concepts/linking phrases already inserted in the structure of a concept map.

- the set of concepts/linking phrases available to students for completion of the task. Constraints on this set can be dived into five categories (adopted from (Grundspenkis, 2011) and supplemented):
  - a full set. Students receive all concepts/linking phrases that are relevant to the task and must be inserted into the given structure of a concept map (“fill-in-the-map” tasks) or must be used for construction of a concept map (“construct-the-map” tasks);
  - an empty set. Students need to define all concepts/linking phrases relevant to the task;
  - a partial set. Students receive only a part of concepts/linking phrases as a list, the other part must be defined;
  - an overfull set. Students receive not only those concepts/linking phrases that are relevant to the task, but also additional concepts/linking phrases that are misleading, because they are incorrect or irrelevant to the problem domain;

- a hybrid set. Students receive a part of concepts/linking phrases relevant to the task and a number of misleading items as a list, but the other part of concepts/linking phrases must be defined.

Figure 5 displays the degree of directedness in relation to constraints on the set of concepts/linking phrases available to students. The degree of directedness decreases in the following order: full set→ overfull set→ hybrid set→ partial set→ empty set. However, location of overfull, hybrid, and partial sets on the directedness continuum may change according to the number of misleading and/or absent items included in them.

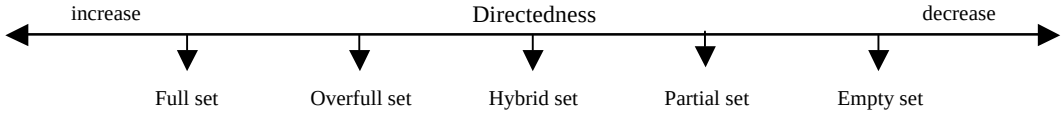

Figure 5. The degree of directedness in relation to the sets of concepts and linking phrases available to students.

Taking into account the task constraints described previously, it is possible to conclude that the degree of task difficulty in both "fill-in-the-map" and "construct-the-map" tasks is influenced by the fact what students should do and what is provided for this activity. However, the degree of task difficulty in "fill-in-the-map" tasks also depends on what is already included in the provided structure of a concept map.

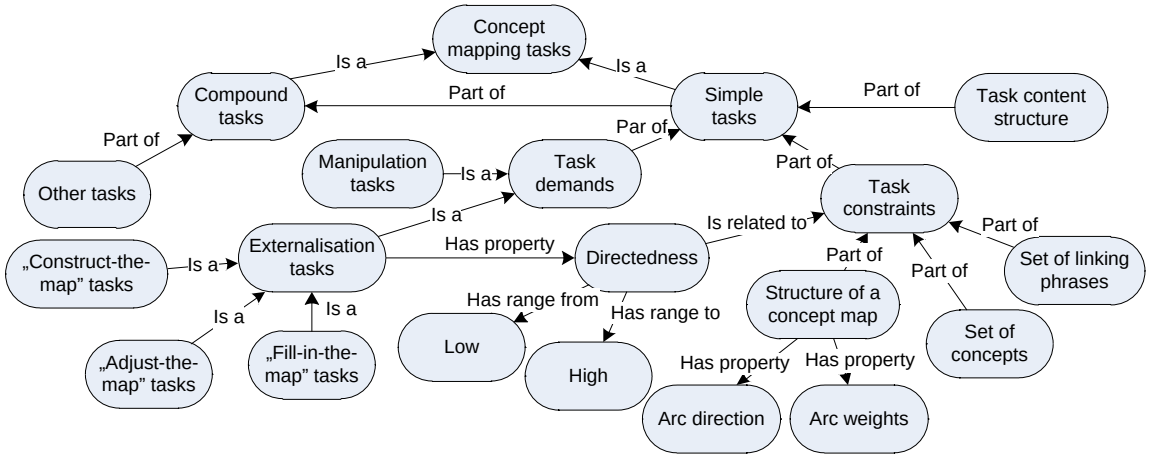

Figure 6. The general view on diversity of concept mapping tasks.

Figure 6 displays a general view on diversity of concept mapping tasks. Table 3 offers a detailed framework for identification of possible concept mapping tasks taking into account task constraints. Impossible combinations are shown as cells with grey shading. Therefore, "construct-the-map" tasks are a combination of an absent concept map structure and:

- one of constraints on the set of concepts available to students;
- one of constraints on the set of linking phrases available to students;
- one type of arc direction (from available variations);
- one type of arc weights (from available variations).

"Fill-in-the-map" tasks, in their turn, are a combination of the following items:

- one type of the full structure taking into account concepts filled in the structure;
- one type of the full structure considering linking phrases filled in the structure;
- one of constraints on the set of concepts available to students (except if the structure is "Full structure with fully filled concepts");
- one of constraints on the set of linking phrases available to students (except if the structure is "Full structure with fully filled linking phrases" and except of using "Absent set" together with any type of the full structure with filled linking phrases);
- one type of arc direction ("Undirected arcs" are used with "Absent set" of linking phrases);
- one type of arc weights.

Constraints on other elements \ Constraints on a concept map structure		Absent structure	Full structure with fully filled concepts	Full structure with partly filled concepts	Full structure with no concepts inserted	Full structure with fully filled linking phrases	Full structure with partly filled linking phrases	Full structure with no linking phrases inserted
Constraints on the set of concepts available to students	Full set		■					
	Partial set		■					
	Overfull set		■					
	Empty set		■					
	Hybrid set		■					
Constraints on the set of linking phrases available to students	Full set					■		
	Partial set					■		
	Overfull set					■		
	Empty set					■		
	Hybrid set					■		
	Absent set					■	■	■
Arc direction	Undirected arcs		■			■	■	■
	Directed arcs: direction is provided in the structure	■						
	Directed arcs: direction is partly provided in the structure	■						
	Directed arcs: direction is not provided							
	Partly directed (Novakian) arcs: direction is provided in the structure	■						
	Partly directed (Novakian) arcs: direction is partly provided in the structure	■						
	Partly directed (Novakian) arcs: direction is not provided							
Arc weights	Homogeneous weights							
	Heterogeneous weights: all weights are provided in the structure	■						
	Heterogeneous weights: weights are partly provided in the structure	■						
	Heterogeneous weights: weights are not provided							

Table 3: The Framework of Concept Mapping Tasks Taking into Account Task Constraints

5 Conclusions and Future Work

The analysis performed shows that concept mapping tasks are extremely different due to the variety of constraints that can be put on elements of a concept map. Therefore, they offer a quite broad spectrum of possibilities to support various assessment needs and peculiar students' characteristics related to construction and externalization of their knowledge structures. In future, several research tasks are planned: a) extraction from the whole set of possible concept mapping tasks a sub-set of tasks that can be processed in automatic way;

b) developing of a mathematical model for evaluation of the tasks selected; c) study on factors determining students' individual differences in construction of knowledge structures. Results of the mentioned research will be used for extending the set of tasks and providing adaptive knowledge assessment in IKAS.

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