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## **WWW-intensive concept mapping for metacognition in solving ill-structured problems**

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**Abstract:** Concept mapping is one of the most intimate and most dynamic learning support activities that needs still a drastic further evolution of methods and tools. WWW-based concept mapping gains momentum quite fast now and needs a solid reviewing of the various approaches and the empirical effects. This article bridges the technological advance of WWW-based concept mapping tools and its more recent effects on learning by problem solving. The results show that it added value manifests in the phases of idea generation and selection. The mapping approach caused a broader perception and a greater diversity of ideas. The conclusion is that further investments are needed to make WWW-based mapping more accessible and integrated in WWW-based learning management systems.

**Keywords:** WWW-based learning tools; concept mapping; problem solving; idea generation.

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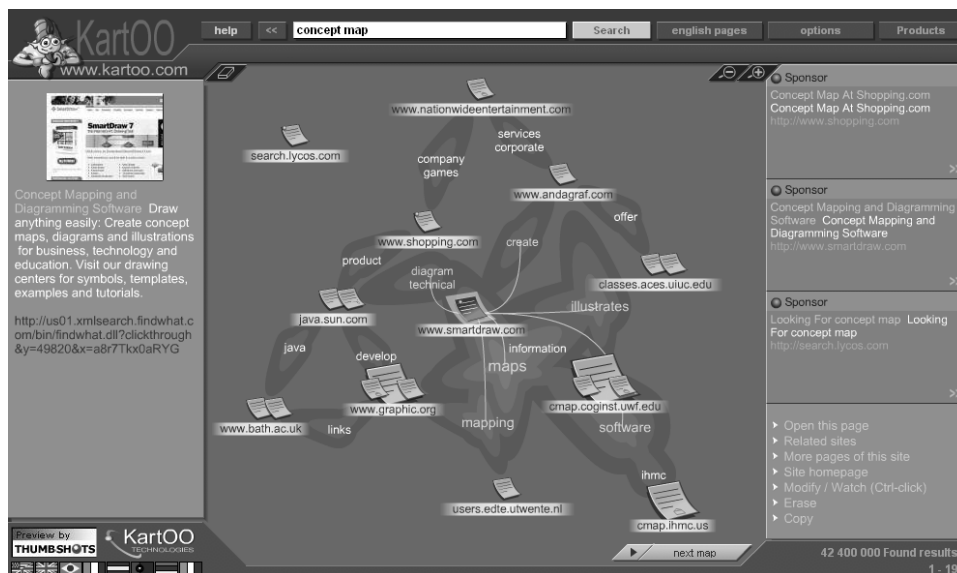
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## 1 Introduction

Concept mapping is widely recognised as strategic method for articulating prior knowledge and stimulate metacognition in the learner. A growing number of conceptual representation tools become available via the WWW lately and it stimulates educationalists to see its pragmatic benefits for collaborative distance learning.

- 1 In the first place there is the family of mapping tools that derive configurational schemes from the hyperlinks as if the user already crawls through the many pages. Instead of the browsing via local hotspots, it is the mapping device that presents a wider landscape so that the learner can take his decisions at a more global meta cognitive level.
  - The first example of resource-based concept mapping is TouchGraph<sup>1</sup> that allows learners to trace the more dominant links (in terms of frequency) that have been created in a certain domain.
  - A second example of it is the WWW-based tool KartOO.<sup>2</sup> It is a meta search engine with visual display interfaces. When you click on OK, KartOO launches the query to a set of search engines, gathers the results, compiles them and represents them in a series of interactive maps through a proprietary algorithm. Given 'Concept Map' as root, it will bring the key arena of sites that elaborate further on Concept Mapping.
- 2 In the second place there are the WWW-based concept mapping tools that allow users to actually build momentary conceptual fields in order to share common or adjacent conceptual frameworks with co-learners at a distance. Examples of these are 'Brain': Dynamic Mind Mapping with Personal Brain.<sup>3</sup> It allows the learner to express the momentary interest and map it unto the vast constellation of existing relations defined by other experts.

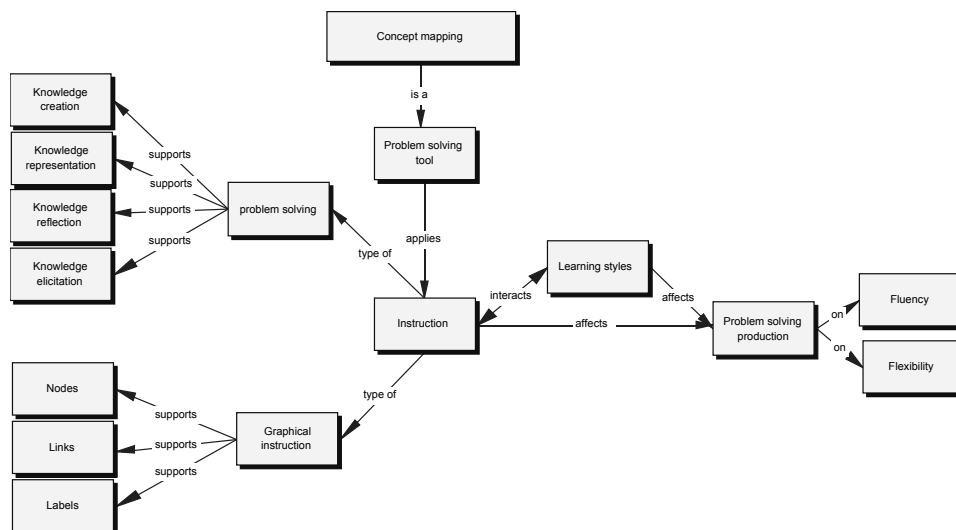


The operational support to learning for solving ill-structured problems is considered as one of the most demanding tasks of the contemporary instructional design paradigm (Jonassen, 2004). It means introduction to specific techniques that facilitate learners to construct appropriate solutions in situations which are characterised with insufficient and sometimes vague information, existence of alternative and often conflicting approaches, lack of clear-cut problem-solving procedures and no agreement upon what can be accepted as an appropriate solution (Jonassen, 2004; Schön, 1996). Some of the techniques that have been discussed are concept map, causal modelling, influence diagrams, expert system shell, modelling dynamic systems (Jonassen, 2004), cognitive flexibility hypertext (Spiro and Jehng, 1990), and questions prompts (Ge and Land, 2004; King, 1991). Concept map is recognised potentially as a powerful problem-solving tool but the discussion on the role of the technique in solving ill-structured problems still has to address a number of substantial questions (Jonassen, 2004; Stoyanov, 2001). Some of them are:

- What are the characteristics of concept map that make this technique an effective and efficient problem-solving tool?
- What are the differences and similarities of concept map compared to other forms of cognitive mapping techniques?
- Are there any individual differences that can affect the concept mapping outputs in a situation of problem-solving?
- What is the role of the instruction in constructing a concept map as problem-solving tool?

An attempt of providing some insights in relation to these questions is given in the following sections. Figure 1 presents a concept map on the content that is a subject of this paper.

**Figure 1** Concept map on concept mapping instruction



This study presents the empirical validation of the role of concept mapping instruction for learning to solve ill-structured problems. The results of the study were operationalised as design solutions implemented in a web-based application, called SMILE Maker (Stoyanov, 2001). The tool stands for solution, mapping and intelligent learning environment. The software guides the learner through the process of problem solving as facilitating her/him in constructing different types of concept maps: map information collection, map idea generation, map idea selection and map idea implementation. For each of these types of maps, specific problem solving heuristics and techniques are proposed, which support the cognitive processes of knowledge elicitation, knowledge representation, knowledge reflection, and knowledge creation. The research presented here focuses on the experimental verification of the concept mapping method, applied in SMILE, but the investigation of learning and problem solving effectiveness of the software application falls behind the scope of this paper.

## 2 Concept mapping as a problem-solving tool

Concept map is defined as a graphical technique to represent the conceptual organisation of a particular subject domain and to grasp the perception of learners on this knowledge structure (Huai and Kommers, 2004; Jonassen *et al.*, 1998; Kommers and Lanzing, 1998; Novak, 1998). The terms of concept map and concept mapping have been used interchangeably. In this study, concept map refers to the result of the concept mapping process. Concept mapping technique has been used mostly as a graphical advanced organiser (Novak and Gowin, 1984; Novak, 1998) and assessment technique (Constantinou, 2004; Fernández *et al.*, 2004; Novak, 1998; Weber, 2004; Willerman and Harg, 1991) from teachers, and as a learning aid for students to organise their declarative and structural knowledge (Gulmans, 2004; Jonassen *et al.*, 1993; Lumer and Hesse, 2004; Lumer and Ohly, 2004; Novak, 1998). There are relatively few reports on the role of concept mapping as a tool that supports learning for solving ill-structured problems (Jonassen, 2004; Stoyanov, 2001). Jonassen (2004) defines concept map as a tool for representing the semantic organisation of problems by learners. He finds important for instructors to encourage students to make semantic concept maps before learners begin to solve problems.

Most of the definitions of concept mapping describe the techniques as a knowledge representation tool (Gulmans, 2004; Huai and Kommers, 2004; Jonassen *et al.*, 1998; Kenedy and McNaught, 1998; Kommers and Lanzing, 1998; Reimann, 1999; Sherry and Trigg, 1996). As a *knowledge representation* tool, concept mapping has some features that could make it a powerful problem-solving tool (Stoyanov, 2001). The technique is an adequate, flexible and intuitive way of externalising the mental model of problem solver. Concept map shows the pattern of knowledge items arranged in the problem space as applying a simple graphical format: nodes represent thoughts and labelled links express their interrelationships. Concept map is a concise, compact and parsimonious technique, which is at the same time rich in information, because of the integration of verbal and visual coding. The technique capitalises on the advantages of graphical representations, without losing the flexibility and richness of the natural language system. Concept map can express a variety of problem-solving representations (facts, analogies, feelings) and a variety of relationships between them (descriptive, structural, causal, metaphorical).

The definition of concept map as a knowledge representation tool reflects only one aspect of psychological conditions involved in problem-solving. Some of the issues attributed to these conditions are restricted processing and high cognitive load due to the limited capacity of working memory, difficulties with searching and retrieval in long-term memory structure, and changing the dominant thinking patterns. These limitations of cognitive system provoke some negative problem-solving effects such as functional fixedness (Duncker, 1945, cited in Eysenck and Keane, 2000; Wertheimer, 1987), problem set (Luchins and Luchins, 1991, cited in Eysenck and Keane, 2000; Wertheimer, 1987) and analysis paralysis (Kaufmann, 2001; von Wodtke, 1993). What makes concept mapping a powerful problem-solving technique is that it is not only knowledge representation tool, but it has also a potential to be knowledge elicitation, knowledge reflection and knowledge changing tool if appropriate instruction is provided (Stoyanov, 2001).

Concept mapping as *knowledge elicitation* tool supports the access to and the search in the long-term memory structures. It allows a quick recognition and retrieval of the available knowledge because of the isomorphic correspondence between map and cognitive structures (Eysenck and Keane, 2000; Wandersee, 1990). Concepts and labels can act as cues for guiding the search through problem-solving space. In addition the visual presentation of mental patterns makes easier pattern recognition. Recognition is a faster cognitive process than retrieval, but also contributes to a more effective retrieval (Eysenck and Keane, 2000). Ill-structured situations not always require development of a completely new solution. The most appropriate solution for a given problem-solving situation may already exist. The question however is to find it as performing broad and deep searching and checking many alternatives.

As *knowledge reflection* tool concept mapping supports the cognitive processes related to effective functioning of working memory. Concept map is a cognitive artifact that allows problem solver to look at his/her mental model and to reflect on the outcomes of thinking. Apart from this support to *reflection-on* individual cognitive reality, as a result, concept mapping supports *reflection-in-action* (Schön, 1996) of cognitive processes as well. The nature of ill-structured problem-solving situations make difficult for people to look inside and control their thinking processes. Two parallel processes are always running – thinking about the problem itself and thinking about thinking on the problem. Concept mapping can be beneficial in such sort of situations as externalising the internal problem-solving patterns and stimulating the self-appraisal metacognitive functions. In this way it enhances the internal locus of control on problem-solving processes.

Concept map has a potential to reduce the cognitive load, which is a recognised threat for a successful learning (Sweller *et al.*, 1998). As a cognitive artifact, concept map is an external extension of working memory. It makes possible for problem solver to grasp complex interactions among thoughts that could otherwise exceed problem solver cognitive capacity. The externalisation of mental problem-solving representations involves effectively perception, which amplifies the performance of memory and thinking. It frees up cognitive resources necessary for memory and thinking.

As *knowledge changing tool*, concept map has a potential to change the dominant thinking pattern and to create a new one (if and when needed) that reflects better the problem-solving situation. The technique allows manipulation of problem-solving representations. As a cultural artifact, concept map mediates the interaction of a problem

solver with the objective problem-solving situation (Vygotsky, 1978). It is a sort of 'transitional object' (Eden and Ackerman, 2002; Lane, 1997) representing mental models, which problem solver can play with. The position of knowledge items and spatial configuration can be changed purposely in order to see different perspectives and to explore new possibilities. This leads to generation of new ideas. Working upon a concept map we are building upon our cognitive structures. While improving, modifying or changing completely the external model of a thinking pattern, we are improving, modifying or changing this pattern effectively. The potential of concept mapping to change the problem-solving patterns in ill-structured situations is a distinguishing characteristic of this technique.

### 2.1 *Concept map as a part of the cognitive mapping paradigm*

Concept mapping is a member of the cognitive mapping family, which includes among other causal mapping (Eden and Ackerman, 2002), dynamic mapping (Vennix, 1997), mind mapping (Buzan and Buzan, 1996), and hexagon mapping (Hodgson, 1999). The discussion on the role of concept mapping in problem solving does not provide sufficient information about the specific characteristics of concept mapping that make it a more appropriate problem-solving tool than the other cognitive mapping formats (Jonassen, 2004). A comparative analysis of the theoretical background, procedures and software of different mapping approaches is given elsewhere (Stoyanov, 2001). For the purposes of this study we provide just a short description of these characteristics of concept mapping as a problem-solving tool.

Although referring to different theories, all of the referred cognitive mapping approaches use a non-linear spatial format as an explicit metaphor to represent the way knowledge items are interconnected. The theories behind the different mapping strategies provide empirical evidence that human mind stores and organise information in a map format. There are however some substantial differences in the way the mapping approaches represent cognitive constructs involved in problem-solving. Concept map is the only mapping technique that allows different formats of spatial organisation of ideas. It can be either hierarchy or network, as network itself opens many possibilities. Causal mapping directly suggests a hierarchical structure, while mind mapping imposes a hierarchy without an explicit reference to this type of organisation. Causal mapping and dynamic mapping apply mostly unlabelled causal links. The graphical organisation of mind mapping suggests structural links. The relationships can be other than structural, but they are not explicit and the reader has to make inferences about their type. Hexagon mapping does not use links at all. Concept map is the only technique that provides opportunity for applying any sort of labelled idiosyncratic links. The graphical conventions of concept mapping make the technique the most flexible and expressive mapping technique (Alpert, 2004; Heeren and Kommers, 1992).

### 2.2 *Mapping software*

Most of the mapping approaches are implemented in specific *software* applications: Inspiration<sup>®</sup> (2003) – concept mapping, Mind Manager<sup>®</sup> (2004) – mind mapping, Decision Explorer<sup>®</sup> (2003) – causal mapping, STELLA 7.0, (2000) – dynamic mapping, and Idons-For-Thinking 2.0 (1999) – hexagon mapping). They provide explicit support for only the *graphical conventions* of a particular mapping approach but not for how a

particular cognitive mapping method can be used for an effective problem solving. It is assumed that the function of cognitive mapping as a problem solving tool is self-evident, it is given by affordance and it is embedded within the graphical functions. Mapping software support mostly knowledge representation features of mapping approaches, but do not support knowledge elicitation, knowledge reflection, and knowledge creation functions. The mapping software applications serve mostly as *graphical* tools but not as *cognitive* tools for problem solving.

### 2.3 Concept mapping and individual differences

The cognitive structures and processes modelled by a concept map have individual dimensions. It should be expected that a concept map reflects the characteristics of the individual constructs involved in problem-solving (Huai and Kommers, 2004; Jonassen, 2004; Oughton and Reed, 2000; Stoyanov, 2001). We should be able to identify these individual constructs' features in the specific graphical organisation of the concept map elements. The taxonomy of individual differences consists of constructs such as level of knowledge, cognitive styles, learning styles, personality traits to list but a few. Important issues related to the individual constructs are their large number and diversity, multi-layers structure, and instability over time, space and task. The reported issues can be managed for research and design purposes through a selection of the stylistic preferences as a representative for individual differences. We use the term 'stylistic preferences' referring to either learning style or cognitive style. Stylistic preferences are an integrative construct including abilities and personality dimensions. Stylistic preferences play an intermediate role between abilities and behaviour.

The research on relationships between concept mapping and styles returns some inconsistent data. Ayersman and von Minden (1995) reported no significant difference among Kolb's learning styles of diverger, assimilator, converger and accommodator (Kolb, 1998) in relation to hypermedia knowledge. In contrast, Oughton and Reed (2000) found an interaction effect between Kolb's learning styles and level of prior hypermedia knowledge on several features of concept mapping production such as number of concepts, number of links, level of depths, preserved concepts, omitted concepts, and added concepts. Assimilators and divergers were the most productive on their maps and had the deepest level of processing on their maps. Huai and Kommers (2004) measured the effect of cognitive styles, knowledge dimensions and concept mapping approaches on learning achievements. The cognitive styles are holist, serialist, un-known styles and versatiles (Pask, 1988). Knowledge dimensions were defined as declarative and procedural knowledge. Two concept mapping approaches were developed: globalistic and specialistic. The globalistic approach was designed to match the holistic dimension of cognitive style. The specialistic concept mapping approach was designed to match the serialistic dimension of cognitive style. The findings of the study do not suggest an effect of concept mapping at cognitive style level. In addition, it was not found whether style's accommodation or compensation affects the learning achievements. In earlier research Huai (2000) assumed relationships between cognitive styles (holist/serialist), type of memory (short-term/long-term), and concept mapping method (serialistic/globalistic) on learning outcomes. She reported a relationship between cognitive style and type of memory. Holists try to compensate their weak short-term memory with globalistic concept mapping approach. Serialists having a good short-term memory adopt a serialistic concept mapping approach.

#### 2.4 Instruction on concept mapping

The consideration of concept mapping as knowledge representation tool bring about the assumption that the instruction on concept mapping applying graphical conventions a sufficient condition that automatically makes the technique an effective problem-solving tool (Jonassen, 2004). Our experience of using concept mapping to support learning to design software applications for educational and training purposes showed that it was not be the case. The instruction based on graphical conventions of concept mapping is a necessary but not a sufficient condition for making concept mapping an effective problem-solving tool. There should be another type of instruction that takes into consideration the characteristics of problem-solving process. It introduces a set of heuristics and more concrete techniques that support the cognitive processes of knowledge elicitation, knowledge representation, knowledge reflection, and knowledge creation in each of the problem-solving phases, namely, analysis of problem situation, idea generation, idea selection and solution implementation. It is this type of concept mapping instruction that transforms the possibility of being an effective problem solving tool into reality. Some of the other cognitive mapping approaches apply a problem-solving instruction in addition to the graphical instruction. Dynamic mapping (Vennix, 1997) uses Delphi method and Nominal group technique. Hexagon mapping (Hodgson, 1999) proceeds with some of the principles and techniques of lateral thinking (De Bono, 1990). The problem related to the type of instruction that makes concept mapping an effective problem solving tool in ill-structured situations brings two hypothetical ideas. One assumes that the instruction on graphical conventions is sufficient condition for making concept map an effective problem-solving tool. Another assumes that the instruction on graphical conventions should be complemented with some problem-solving heuristics and techniques. The two instructions together constitute the necessary and the sufficient conditions for concept mapping to be an effective problem-solving tool. The graphical instruction on concept mapping applies the classical procedure introduced by Novak and Gowin (1984). The problem-solving instruction, developed for the purposes of this study, took into consideration the problem-solving process. For each of the stages of problem-solving process, a number of heuristics was suggested (for details see Stoyanov, 2001, pp.175–177). The set of heuristics was based on the strengths of the rational approaches to problem-solving such as explicitness, generality and soundness (Wagner, 1992), but also took into account the intuitive, non linear and thinking-while-doing way people approach problems (Mintzberg, 1992; Schön, 1996; Wagner, 1992). The problem solving guidelines reflected brainstorming principles (Osburn, 1963, cited in Van Gundy, 1997), rational problem-solving approach (Kepner and Tregoe, 1981, cited by Van Gundy, 1997), synectics method (Gordon, 1961, cited in Van Gundy, 1997), and lateral thinking techniques (De Bono, 1990). The heuristics were aimed at supporting knowledge elicitation, knowledge representation, knowledge reflection and knowledge changing. Some randomly taken examples of heuristics that support *knowledge elicitation* during problem-solving phase of *analysis of the situation* are:

“Try to scan everything you know about the problem situation. Map everything that comes spontaneously to your mind, as one items is built upon another. The items might be existing solutions, facts, hunches, metaphors, feelings. Produce as many information items as possible. Avoid any attempt to judge them during the process of free association.”



Some examples for *knowledge reflection* heuristics are:

“Make an evaluation trip on the map. Remove or change (if it is necessary) some of the nodes and some of the links. Try to improve your map.”

Some examples for *knowledge representation* guidelines are:

“Try to make clusters. Draw and label links between items. The links can be descriptive (*is a*), structural (*part of, belongs to*), causal (*leads to, influenced by*), or metaphorical (*like*).”

An example for *knowledge changing heuristic* is ‘Change the places of the nodes in the map, if necessary’.

Some guidelines that support *knowledge elicitation* during *idea generation* phase are as follows:

“Look at the map analysis of situation that just has been made. Start to formulate solution by scratch, as many as possible. Write down everything that pops-up to your mind without any judgment.”

An example for *knowledge changing heuristic* during the idea generation is the following:

“Take randomly one of the marginal concepts and put it at the very central place of the map. Try to reconfigure the map from this new perspective. Use the new vision as a stimulus for a free association in order to generate as many ideas as possible.

Play with labels. Randomly select a pair of nodes and change the links’ label. Use this as a provocation for producing as many solutions as you can.”

An example for *knowledge representation* heuristics during the idea generation is the following:

“Draw a resulting map containing all ideas generated. Link the nodes and label the links as *is a; part of, like; leads to, and etc.*”

An example for *knowledge reflection* heuristic during the idea generation phase is the following:

“Try to find a trend or pattern among the ideas you have generated. Is it possible to make clusters? If you find repetition of some of the ideas, it should attract your attention. Try to add some more ideas.”

In addition to investigating the effectiveness of the concept mapping instruction method, we want to determine the role of individual differences in each of the two hypothetical conditions. To test the validity of the assumptions we design and conduct an experiment. The research questions that are going to be addressed are as follows:

- What is the effect of type of concept mapping instruction on solving ill-structured problems?
- What is the effect of individual differences on the construction of concept maps given an ill-structured problem-solving situation?

### 3 Method

The experimental method applied a factorial experimental design ( $2 \times 2$ ) with a post-test control group. This experimental design was selected because a random assignment to the conditions was possible at a certain stage. The combination of random assignment and a control group served to eliminate the majority of threats to both the external and internal validity of the study. Although the proportion of dropouts was reported as a potential threat to internal validity, not controlled for this type of design, it did not prove to be a problem in the current study. The research was conducted in a one-day session and the size of groups remained constant throughout the duration of the study.

The experimental design included two independent variables: type of instruction on concept mapping and learning style. The type of instruction had two levels: the classical concept mapping instruction method and the new concept mapping instruction method. The new concept mapping instruction method introduced a set of problem-solving heuristics in addition to the concept mapping graphical conventions.

The experimental design defined learning style as a second independent variable. It had also two levels: doers and thinkers. Learning style should be controlled because of the possibility of being a source of alternative explanation of the effect of instruction on mapping production, if found. This variable was included in the experimental design schema as a second independent variable because it was expected that it can be a good predictor for a possible differential effect on mapping production and a possible interaction effect with the type of concept mapping instruction.

The dependent variable in this study was concept mapping production. The operationalisation of the variable is based on the approach of Novak and Gowin (1984) in scoring concept maps and the criteria for creative thinking developed by Guilford (1967), both adapted for measuring the effectiveness of concept mapping instruction.

The operationalisation of the dependent variable included two criteria, each having several indicators. These criteria were broad perception and divergence. Broad perception defined the extent to which problem solver represents comprehensively the problem situation. The indicators that described this criterion were as follows:

- Fluency
  - a *number* of nodes
  - b *number* of links
- Flexibility
  - a *variety* of nodes – facts, data, metaphors/analogies, personal experience, opinions, hypotheses, feelings
  - b *variety* of labels – descriptive, structural, causal, interrogative, and remote associations
  - c *variety* of links – one-directional, bi-directional, and cross-links.

Divergence was defined as the extent to which problem solver produced alternative solutions. The indicators that described this criterion were:

- Fluency – *number* of ideas
- Flexibility – *variety* of ideas: ready-made solutions, elaboration, and unconventional ideas.

The study tested two hypotheses. The first hypothesis states that the experimental group using the new method for concept mapping instruction will score significantly higher on mapping production than the control group, which applies the classical concept mapping instruction method. According to the second hypothesis individual differences in learning styles will predict the differences in mapping production and will generate an interactive effect with the type of instruction.

### *3.1 Subjects and instrument*

Fifty-two fourth-year undergraduate students were tested for their learning style. Thirty-two of them were randomly selected and then were equally assigned to the experimental and the control group, according to their learning styles. As a reinforcement to increase the motivation of the students to participate in the experiment, several demo versions of mapping software tools were installed for free to be used after the experiment.

The Learning Style Questionnaire (LSQ) of Honey and Mumford (1992) was used to measure learning styles of students. It consists of 80 items to identify four learning styles: activist, reflector, theorist, and pragmatist. The instrument is a psychometrical validation of Kolb's (1998) experiential theory but provides better internal consistence of items than the original Kolb's Learning Style Inventory (see for more details de Ciantis and Kirton, 1996). The test-retest reliability of the LSQ is reported to be high – 0.89. In order to ensure better representation of learning styles for the purposes of this experiment, the four scales were merged into two – Thinkers (Theorists and Reflectors) and Doers (Activists and Pragmatists). Honey and Mumford (1992) recommended reducing the four styles to two for research purposes.

The reliability of mapping production coding was checked as well. Firstly, two evaluators independently coded six maps each (three from the experimental group and three from the control group) and compared the results of their scoring. The intercoder reliability was a relation between the number of agreements and the total number of agreements and disagreements (Miles and Huberman, 1994). The intercoder reliability initially got the value of 80%. Because this was assumed as not a very high reliability, the two evaluators discussed the value of each of the indicators in order to make closer their judgments. The discussion increases the value of the intercoder reliability up to 95%.

### *3.2 Procedure*

The learning style questionnaire was distributed among the subjects to be filled in. Based on the results, the students were proportionally assigned to the control and the experimental groups in order for both learning styles (thinkers and doers) to be equally represented.

The students in the control group were introduced to the classical concept mapping method. The experimental group had to apply the new concept mapping instruction method.

A case to be solved was presented to the students in both the control and the experimental group and they were asked to use the procedures they had been introduced to solve the case. The case, called the 'George's Career Dilemma' represents a situation in which a last year university student is confronted with a problem to take decision about his future.

#### 4 Results

Two-way analysis of variance was chosen as an appropriate statistical procedure for the factorial experimental design applied in this study. The fixed factors were concept mapping instruction and learning style. The dependant variable was mapping production. An alpha level of 0.05 was used for all data analysis.

The experimental group scored significantly higher than the control group on the indicator *fluency of nodes* of the broad perception criteria –  $F(1, 28) = 6.297$ ,  $p = 0.018$ . (See Table 1 for the direction of concept mapping instruction effect).

**Table 1** Mean figures of broad perception – nodes

Nodes	M		SD	
	Classical	New	Classical	New
Number of nodes	10.7	16.8	3.5	8.8
Variety of nodes	2.1	4.7	0.4	1.3
Facts	71.9	48.5	7.6	10.2
Opinions	27.9	13.9	7.6	10.6
Feelings	0.6	14.6	2.2	7.2
Metaphors and analogies	0.3	4.2	1.3	5.2

Note: N = 32 (Classical concept mapping instruction – 16; New concept mapping instruction – 16)

The subjects in the experimental group produced considerably more information items than the subjects in the control group. The experimental group also demonstrated significantly higher results on the *flexibility of nodes* –  $F(1, 28) = 55.446$ ,  $p = 0.0001$ . The distribution of the different types of nodes shows that the students in the experimental group included relatively much more statistical data and figures –  $F(1, 28) = 12.802$ ,  $p = 0.000$ , personal experience –  $F(1, 28) = 11.510$ ,  $p = 0.002$ , hypotheses –  $F(1, 28) = 13.810$ ,  $p = 0.001$ , feelings –  $F(1, 28) = 62.837$ ,  $p = 0.000$ , and metaphors and analogies –  $F(1, 28) = 8.269$ ,  $p = 0.008$ , than the students in the control group. No one of the maps in the control group contained the following types of nodes: statistical data and figures, personal experience, and hypotheses. The perception of the problem space in the control group was dominated mostly by facts –  $F(1, 28) = 50.948$ ,  $p = 0.000$  and opinions –  $F(1, 28) = 17.372$ ,  $p = 0.000$ . The data show that the new concept mapping instruction method stimulates students in the experimental group better to express the complexity of their problem-solving representations than the students applying the classical concept mapping instruction. Students in the experimental group use not only facts but also feelings, metaphors and analogies, and assumptions types of nodes.

There was not a significant difference between the experimental and the control group on the indicator *fluency of links* (Table 2 presents mean values of the Broad Perception – links indicators).

**Table 2** Means figures of broad perception – links

<i>Links</i>	<i>M</i>		<i>SD</i>	
	<i>Classical</i>	<i>New</i>	<i>Classical</i>	<i>New</i>
Number of links	17.8	17.9	5.7	9.7
Variety of links	2.4	1.6	0.6	0.8
One-directional links	76.4	95.2	15.8	8.8
Bi-directional links	12.8	2.2	12.7	5
Cross-Links	10.2	4.6	8.2	7

Note: N = 32 (Classical concept mapping instruction – 16; New concept mapping instruction – 16)

As the students in the experimental group produced more nodes, the students in the control group use relatively more links per node. The subjects working with the classical concept mapping instruction scored significantly higher than their fellows in the experimental group on the relative number of bi-directional –  $F(1, 28) = 9.965$ ,  $p = 0.004$ , and cross-links –  $F(1, 28) = 5.029$ ,  $p = 0.033$ . The students in the experimental group use mostly one-directional links –  $F(1, 28) = 16.490$ ,  $p = 0.000$ . A possible explanation might be that subjects using the classical method were forced to use the whole repertoire of possible links because they had to represent everything on one sheet of paper. The students in the experimental group had more room to place their problem-solving representations because of the instruction to make at least two maps – one for analysis of problem situation and one for idea generation. This particular feature of the new concept mapping instruction gave the subjects in the experimental group more memory space, mapped into different sections – analysis of problem situation and idea generation. While the traditional method put all the problem-solving activities in one picture, the new concept mapping instruction created a picture of the whole problem-solving process, sharing the cognitive load between the problem-solving stages. While the simplicity of the types of links freed up the memory processes, the complexity of the labels' structure provided a deeper perception of the problem-solving space.

The variety of link labels –  $F(1, 28) = 5.645$ ,  $p = 0.025$ , was greater in the experimental conditions (Table 3 shows the mean figures of links' labels).

**Table 3** Means figures of broad perception – labels

<i>Labels</i>	<i>M</i>		<i>SD</i>	
	<i>Classical</i>	<i>New</i>	<i>Classical</i>	<i>New</i>
Variety of labels	2.8	3.4	0.6	0.9
Descriptive labels	53.3	25.9	24.4	16.6
Structural labels	7	14.2	7.1	7.8
Causal labels	4.5	7.6	3.6	3.6
Interrogative labels	0.4	2.8	1.5	3.9
Remote associative	0	4.9	0	5.3

Note: N = 32 (Classical concept mapping instruction – 16; New concept mapping instruction – 16)

The students in the classical concept mapping instruction group used predominantly descriptive types of links' labels –  $F(1, 28) = 12.948, p = 0.001$ . They did not use remote association labels at all. The experimental group used more structural –  $F(1, 28) = 8.483, p = 0.007$ , causal –  $F(1, 28) = 6.192, p = 0.019$ , interrogative –  $F(1, 28) = 5.358, p = 0.028$ , and remote associative –  $F(1, 28) = 13.064, p = 0.000$ , links. The new method used a more complex verbal code combined with a simpler link structure. It provided a deeper perception of the problem space while reducing the cognitive overload.

The experimental group was superior to the control group in regard to the criteria of divergence. The scores on number of ideas,  $F(1, 28) = 20.171, p = 0.000$ , and variety of ideas,  $F(1, 28) = 9.031, p = 0.006$ , were significantly higher than the same indicators of the control group. (See Table 4 for some descriptive statistics data).

**Table 4** Means for indicators of divergence

<i>Divergence</i>	<i>M</i>		<i>SD</i>	
	<i>Classical</i>	<i>New</i>	<i>Classical</i>	<i>New</i>
Number of ideas	3.3	12.5	1.5	8.6
Variety of ideas	1.1	1.9	0.3	1

Note: N = 32 (Classical concept mapping instruction – 16; New concept mapping instruction – 16)

Certainly the results were expected as far as the control group did not get an explicit instruction of using all these types of nodes, links and types of labels. However, the data revealed at least three important facts:

- 1 the new concept mapping instruction worked and supported problem solving performance
- 2 with the classical concept mapping method, people tend to use particular types of nodes, links, and labels
- 3 the expressiveness of knowledge representation can be improved.

The analysis of the learning style variable showed that Thinkers tended to use significantly more structural types of links than the Doers –  $F(1,28) = 4.419, p = 0.045$ . They also formulated substantially more assumptions items than doers. The result is close to being a significant at the 0.5 level of probability –  $F(1,28) = 3.851, p = 0.060$ . Thinkers naturally tend to classify information and to present it into clusters. They tend also to generate more hypotheses. A good prerequisite for this is a well-established structure. Doers expressed more feelings in the perception of the problem-solving space –  $F(1,28) = 4.047, p = 0.054$ . This is probably because they are more extravert-oriented people. With the new instruction Thinkers reduced considerably the number of cross-links –  $F(3,26) = 5.722, p = 0.024$ . Thinkers applying the classical concept mapping approach needed more cross-links to express the structural complexity of the problem-solving space. The new instruction gave them opportunities to distribute the structural complexity among several maps.

The data showed no interaction effect between the two independent variables Instruction and Style on the dependent variable of Map Production. The new concept mapping instruction proved to have a main effect across all learning styles.

## **5 Discussion**

The experimental results support the hypothesis that the new concept mapping instruction method is significantly better than the traditional concept mapping instruction in a problem solving situation. The question however is how and why it is a better instruction method for solving ill-structured problems. The new instruction method proves to be more effective in the analysis of problem situation and the idea generation. It enables a broaden perception with more and diverse information items and more complex labels on the links. The new problem solving instruction promotes a broader and more complex cognitive structure with a dominance of the structural, interrogative, causal and remote associative types of links. The classical concept mapping method used more simple, descriptive types of links.

The new concept mapping instruction gives more space for scanning not only cognitive but also affective problem-solving representations. The psychological distance between the types of information items on the scale of objectivity-subjectivity is larger in the experimental group.

Data, for example, are very objective and feelings are very subjective. This increases the possibility for breaking the fixedness of existing patterns and stimulates creative combinations in the idea generation phase.

The students in the experimental group knew that they have to start with the map analysis of problem situation and then they have to continue with constructing the map idea generation. The externalisation of cognitive and affective structures by a sequence of maps involves perception. Perception itself takes over some of the mental tasks during problem-solving, thus contributing to reducing the memory overload. It makes the reasoning processes easier and more flexible. While the traditional method draws one picture trying to include all problem-solving activities, the new type of instruction creates a picture of the whole problem-solving process distributing the cognitive load between the problem-solving stages. The new method brings a perspective and a direction to the activities. It is a cognitive aid for guiding and planning through the stages of problem-solving. The problem-solving instruction supports not only reflection-on a particular map production (analysis of situation, or idea generation). The students in the experimental group produced several versions of the map analysis of problem situation and the map idea generation as a result of reflection on their mapping production.

Although the data did not support the assumption for an interaction effect between concept mapping instruction method and learning style, the experimental results suggested that the new concept mapping instruction method brought a general beneficial effect regardless of different learning styles. It tends to develop skills, which are not prerogative to no one of the styles. Thus the method has the potential to develop a comprehensive versatile style.

The new concept mapping instruction method produced better results than the classical concept mapping instruction because the new method operationally supported the cognitive conditions of knowledge elicitation, knowledge reflection, knowledge representation and knowledge changing. In general, the number of nodes and links of broad perception criterion and number of ideas of divergence criterion are indicators of knowledge elicitation. The variety of nodes, links (broad perception), and ideas (divergence) are operationalisations of the knowledge representation.

Knowledge reflection can be expressed by the extent to which clusters and patterns are identified. Knowledge changing implies a number of original solutions that have been generated (divergence).

### *5.1 Knowledge elicitation*

The new concept mapping instruction method offers special techniques for a broad and deep retrieval of cognitive and affective structures during the analysis of problem situation. In the idea generation phase the new instruction method stimulates production of many alternative solutions. The heuristics that it applies are combinations between some problem-solving techniques and the specific characteristics of cognitive mapping.

### *5.2 Knowledge representation*

The new concept mapping method promotes a variety of problem-solving types of representations and a variety of links between them to build a meaningful network when exploring a problem-solving space. It stimulates using not only *objective* (facts, statistics) but also *subjective* (feelings, intuitions, assumptions) knowledge items. The method manages the complexity of a problem-solving situation through a set of different types of links: descriptive, structural, causal, and remote associative. The new concept mapping method has a capacity to represent very rich picture of a problem situation as combining verbal and visual coding within a simple graphical format. The externalisation of the mental problem-solving representations frees up and extends the limited capacity of working memory thus reducing the cognitive overload.

### *5.3 Knowledge reflection*

The new instruction method on concept mapping makes the internal problem-solving representations explicit. A problem solver is able to reflect-on the results and the process of problem-solving. The new concept mapping instruction method offers some guidelines and techniques for organising the problem-solving space in a particular way. Mostly it is the case of some convergent activities within each of the phases of the method. Knowledge reflection, for example, is supported by the suggestions for reorganising the problem space, more specifically, clustering some of the items and eliminating others.

The visualisation of the problem space through cognitive maps helps the manipulation of the knowledge items in a variety of ways. Because of the close correspondence between internal mental structures and the external mode of their representation one could change the way she or he looks at the problem.

### *5.4 Knowledge changing*

The opportunity that the new concept mapping instruction provides for a manipulation of nodes in the maps can change dominant thinking patterns and create new ones. The new method proposes some easy to apply techniques that stimulate creating of original and unconventional ideas. The new concept mapping instruction challenges the assumption that it is not possible to modify old pattern in such extent that it can result in creating a perfectly new one (De Bono, 1990).



There are not sufficient data to claim that learning style is a strong predictor for a differential effect on mapping production. However, some of the figures in the analysis of the mapping production suggest that learning style preferences should not be ignored. The analysis did not confirm the hypothesis predicting an interaction effect between the type of instruction and learning style. There might be two possible explanations for not confirming this hypothesis. The first one reflected the fact that the experiment modelled a situation, which was dealing primarily with problem-solving and in a less extent with learning. The second reason was the selection of a right measuring instrument. Although the Learning Style Questionnaire (Honey and Mumford, 1992) solved some of the reliability problems of Learning Style Inventory (Kolb, 1998), it still returned inconsistent data due to measuring three different independent constructs: style, level and process (see for more details de Ciantis and Kirton, 1996).

## **6 Conclusions**

The instruction on concept mapping that includes problem-solving heuristics proved a better approach in ill-structured problem situations than the classical concept mapping instruction. The new instruction on concept mapping creates conditions for effective knowledge elicitation, knowledge representation, knowledge reflection and knowledge changing. However, the experimental results should be carefully generalised as more research is needed not only related to concept mapping instruction, but also to the role of instruction on other problem-solving tools.

We reported data related to the role of concept mapping instruction only in the analysis of problem situation and the idea generation phases. The problem-solving process includes additionally at least the phases of idea selection and solution implementation. We have some data about the role of problem-solving instruction in these problem-solving phases. However, the graphical techniques used in the idea selection and the solution implementation were not properly concept maps. Matrix for example seemed more appropriate graphical technique for idea selection. A sort of PERT diagram was used for the solution implementation phase. It would be useful to study the effectiveness of different graphical techniques, including concept mapping, for selecting ideas and implementing of the solutions. Individual differences can be tested also as a predictor for the preferences of learners to particular graphical technique. Further research on concept mapping instruction should optimise some of the experimental conditions developed for the purposes of the current study. The coding of the types of nodes needs an improvement. The indicators for knowledge reflection should be explicitly included in the map production scoring schema. Having clusters and different versions of maps' structures could be indicators for knowledge reflection.

We gave students in this study a domain independent problem with an idea to include experimental subjects from other faculties and universities. Follow up research should challenge students with a domain specific problem. For our reference situation such a problem could be designing a website for educational or training purpose.

The experiment for determining the role of instruction for solving ill-structured problems reflected primarily problem-solving as learning being a secondary concern. Further research should better model the situation of learning to solve ill-structured problems. The individual differences should be better represented through a selection of an appropriate instrument.

Most of the mapping approaches are supported by software (Inspiration<sup>®</sup>, 2004; Mind Manager<sup>®</sup>, 2004; Decision Explorer<sup>®</sup>, 2004; STELLA 7.0, 2000; Idons-for-Thinking 2.0, 1999), which makes easier and more efficient the construction of a map and the manipulation of nodes and links. Testing the effectiveness of the instruction embedded in different mapping software applications could be the next research challenge.

Further research can include on a conceptual level the assumption of a possible interaction between the indicators of mapping production. The statistical test should check the Sums-of-Squares and Cross-Products (SSCP) matrices for determining the effect of type of instruction on the means of various groupings of a joint distribution of these indicators.

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## Notes

- 1 TouchGraph for visualising dynamic patterns in WWW-based references <http://www.touchgraph.com/news.html>.
- 2 KartOO is the WWW-based concept view on topics as learners develop their learning plans <http://www.kartoo.com/>.
- 3 Brain: 'Dynamic Mind Mapping with Personal Brain' <http://www.thebrain.com/LPS/PBMM/>.