Concept mapping instrumental support for problem solving

Slavi Stoyanov*

Open University of the Netherlands, OTEC,
P.O. Box 2960, 6401 DL Heerlen, The Netherlands
E-mail: slavi.stoyanov@ou.nl
*Corresponding author

Piet Kommers

Faculty of Behavioural Science,
University of Twente,
P.O. Box 217, 7500 AE Enschede, The Netherlands
E-mail: P.A.M.Kommers@edte.utwente.nl

Abstract: The main theoretical position of this paper is that it is the explicit problem-solving support in concept mapping software that produces a stronger effect in problem-solving performance than the implicit support afforded by the graphical functionality of concept mapping software. Explicit problem-solving support activates cognitive functions such as knowledge representation, knowledge elicitation, knowledge reflection and knowledge creation. Concept mapping graphical instruction supports knowledge representation only. This paper reports on an experimental study that tests this assumption as measuring the effect of two types of concept mapping software on problem-solving performance, mapping production and perceived problem-solving effectiveness of 47 students randomly assigned to an experimental and a control group .The results validated empirically the theoretical position as the group that used concept mapping software with explicit problem-solving support scored significantly higher on problem-solving performance and on the most of the indicators of mapping production and perceived effectiveness of concept mapping software.

Keywords: cognitive mapping; concept mapping software; problem-solving support.

Reference to this paper should be made as follows: Stoyanov, S. and Kommers, P. (2008) 'Concept mapping instrumental support for problem solving', *Int. J. Cont. Engineering Education and Lifelong Learning*, Vol. 18, No. 1, pp.40–53.

Biographical notes: Slavi Stoyanov is an Assistant Professor at the Educational Technology Expertise Center at the Open University in The Netherlands. He has a PhD degree on Instructional Technology from University of Twente, The Netherlands. His prior research interest includes cognitive mapping, learning to solve ill-structured problems and individual differences in learning.

Piet Kommers is an Associate Professor at University of Twente, The Netherlands. His interest and prior research are conceptual design and visual communication. His dominant paradigm is that media provoke alternative new ways of living and stimulate youngsters to expose themselves in new literary and iconic genres.

1 Introduction

The potential of concept mapping to provide an effective and efficient support for ill-structured problem solving has been reported in a number of studies (Novak, 1998; Jonassen, 2004; Stoyanov and Kommers, 2006). On conceptual level, however, there are still some issues to be addressed, which affect the operational solutions provided by concept mapping as a cognitive tool for problem solving. These issues are related to the psychological constructs involved and supported by concept mapping, the specific characteristics of concept mapping compared to other cognitive mapping approaches, the effect of types of concept mapping instruction and the role of concept mapping software in problem solving. The study first discusses these issues. Then it reports on an experimental study on the effectiveness of a concept mapping software application for problem solving that provides instrumental solutions to these issues. The study concludes with a discussion on the results of the study.

2 Concept mapping support for knowledge representation, elicitation, reflection and creation

Most of the studies define concept mapping as a knowledge representation technique (Sherry and Trigg, 1996; Jonassen et al., 1998; Kennedy and McNaught, 1998; Reimann, 1999; Gulmans, 2004; Huai and Kommers 2004). This definition reflects only one of the characteristics of concept mapping as a problem-solving tool. Apart from being a technique that supports knowledge representation, concept mapping is also a technique for knowledge elicitation, knowledge reflection and knowledge creation (see for details Stoyanov and Kommers, 2006). Concept mapping as a knowledge-representation technique is a concise and intuitive way of externalising the mental models of the problem-solver as the technique proposes a simple graphical format, which combines both visual and verbal coding. Concept mapping, as a knowledge-elicitation technique, allows a quick recognition and retrieval of the available knowledge because of the isomorphic correspondence between the concept maps and the activated cognitive structures. Concept mapping as a knowledge-reflection technique effectively supports self-appraisal on problem-solving process and results. It also involves perception that amplifies memory and thinking as creating more space for cognitive resources. Concept mapping as a knowledge-creation technique has a potential for an effective and efficient combination of different ideas and construction of alternative solutions.

3 Concept mapping and other mapping approaches

Concept mapping is only one of the forms of cognitive mapping. The class of cognitive mapping includes, among others, mind mapping (Buzan and Buzan, 1996), causal mapping (Eden and Ackerman, 2003), hexagon mapping (Hodgson, 1999) and dynamic mapping (Vennix, 1997), to list but a few. Identifying the differences and similarities of these mapping approaches provides a better understanding of the potential of concept mapping as a problem-solving technique. 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 refer to only two of the distinguishing characteristics of concept mapping. Concept mapping is enough flexible and intuitive to (a) allow different graphical formats for the spatial organisation of ideas and (b) provide opportunities for applying any sort of idiosyncratic links between nodes – descriptive, structural, causal and metaphorical.

The technique benefits from the other mapping approaches as borrowing some of their specific functions. For example, some of these approaches implement an instruction for problem solving that contains particular heuristics and techniques. Dynamic mapping (Vennix, 1997) uses Delphi and nominal group techniques while hexagon mapping (Hodgson, 1999) includes some of the principles and techniques of lateral thinking (De Bono, 1990).

4 Graphical versus problem-solving instruction

The graphical convention in the instruction for drawing a concept map is a necessary but not sufficient condition for making concept mapping an effective problem-solving tool. The instruction on graphical conventions should be coupled with an instruction that includes a set of heuristics and concrete problem-solving techniques. It is the problem-solving instruction that produces significant difference in the ill-structured problem-solving solutions (Stoyanov and Kommers, 2006).

5 Implicit versus explicit instrumental support

Most of the *software* applications for different cognitive mapping forms (Inspiration®, 2003, for concept mapping; Mind Manager®, 2003, for mind mapping; Decision Explorer®, 2003, for causal mapping; STELLA 7.0, 2000, for dynamic mapping and Idons-For-Thinking 2.0, 1999, for hexagon mapping) provide explicit support for only the *graphical conventions* behind a particular mapping approach but not for how this 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 as being embedded within the graphical functions of the tools. Concept mapping software mostly supports the knowledge-representation functions whereas knowledge elicitation, knowledge reflection and knowledge creation are hardly considered possibilities. Concept mapping software applications are used mostly as drawing tools whereas their potential as cognitive tools for problem solving has not been explored comprehensively.

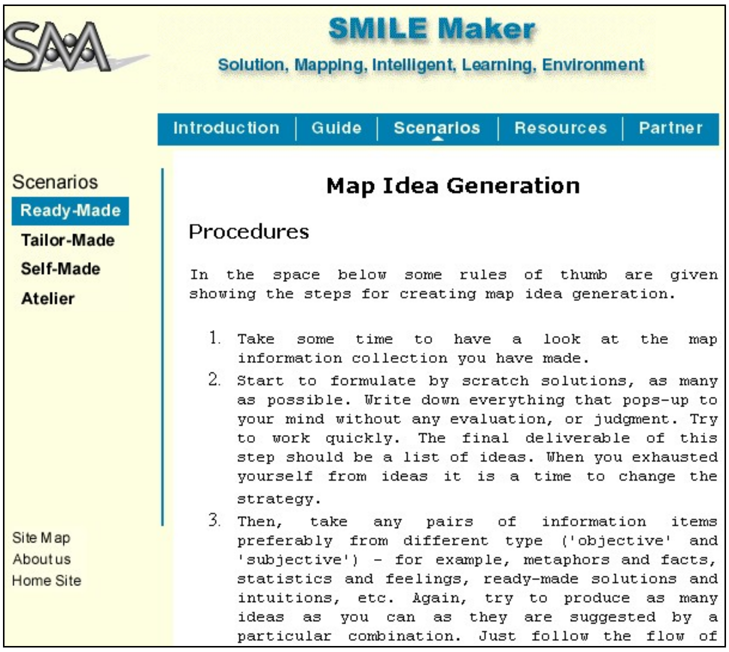
This study investigates the role of concept mapping instrumental support for solving ill-structured problems. Instrumental support means using concept mapping software. It is a follow-up study (Stoyanov & Kommers, 2006) but now with a special attention to the role of concept mapping software. The current study attempts to provide empirically grounded answers to the following research question: What is the effect of concept mapping instrumental support on problem solving performance?

In order to explore this research question we create an experimental situation in which two types of concept mapping instrumental support for ill-structured problem solving are compared. The first one presents mapping software, in which problem-solving support is assumed to be given by affordance – through the graphical functionality of the application. For example, both Inspiration (2003) and Mind Manager

(2003), the most popular mapping software applications in education, propose an option for brainstorming – quick entering of nodes. There is, however, no information about the principles and rules of brainstorming and how to apply them in a problem-solving situation. The second type of instrumental support presents a cognitive mapping software application that provides explicit problem-solving support in terms of specific heuristics and techniques. This software was specially developed for the purposes of this study. It operationalises the ‘hypothetical’ construct of explicit problem-solving support, making it visible and ‘touchable’ in the application. The software guides in constructing map information collection, map idea generation, map idea selection and map idea implementation as deliverables of phases of the problem-solving process. For each of these types of maps, specific problem-solving heuristics and techniques are proposed, supporting the cognitive processes of knowledge elicitation, knowledge representation, knowledge reflection and knowledge creation. The description of these guidelines and procedures is presented elsewhere (Stoyanov, 2001; Stoyanov and Kommers, 2006).

The cognitive mapping software application is called SMILE Maker. SMILE stands for Solution, Mapping and Interactive Learning Environment. Figure 1 gives an idea how it looks like. SMILE Maker is a performance support system combining problem solving and learning. The problem-solving method of SMILE Maker can be learned while being applied. This study focuses on SMILE Maker as a problem-solving tool, as the purposes, characteristics and functions of its learning environment are not discussed here.

Figure 1 The SMILE Maker idea generation



6 Method

The independent variable in this experiment is instrumental support for cognitive mapping with two levels: Inspiration (2003) and SMILE Maker. SMILE Maker offers explicit problem-solving support, whereas Inspiration includes implicit or embedded problem-solving support. The dependent variable is problem-solving performance (solution of a case, mapping production and reflections of the participants). The dependent variable is further defined in more concrete terms such as (a) a score on an expert scale for a successful *solution of an ill-structured case*; (b) a score on *mapping production* according to the criteria of broad perception and divergence and (c) scores on scales of a *reflective questionnaire*. The experimental design can be defined as ‘randomly assigned experimental and control groups with post-test only’. The control group was introduced to Inspiration. The experimental group worked with SMILE Maker. Both groups were confronted with an ill-structured case. At the end of the session the students filled out a questionnaire constructed to collect their reflections on the problem-solving method they applied.

The first hypothesis reflects the relationship between the two-level instrumental support and the performance on the case. The hypothesis states that the experimental group, using SMILE Maker, will score significantly higher than the control group, using Inspiration, on experts’ judgment on the extent to which the solution of the case is successful.

The second hypothesis reflects the relationship between the type of instrumental support and the mapping production. The operationalisation of the mapping production modifies the scoring schema applied in similar studies (Stoyanov, 2001; Stoyanov and Kommers, 2006). This schema is based on the approach of Novak and Gowin (1984) in scoring concept maps and on the criteria for creative thinking developed by Guilford (1967), both adapted for measuring the effectiveness of concept mapping instruction. The current study includes, in addition, some experts’ judgment on some indicators of the mapping production. The operationalisation of the mapping production includes a number of criteria and indicators described as follows:

1 *Broad perception* – the extent to which the participants comprehensively elicit, represent and reflect the problem situation

2 *Number of nodes* – all nodes in a concept map

3 *Fluency of nodes* – how broadly the problem is elicited and represented according to a 5-point expert scale (1 is the lowest, 5 is the highest)

4 *Variety of nodes* – how many different types of nodes (facts, assumptions, feelings and metaphors) are used

5 *Flexibility of nodes* – effective use of variety of nodes to represent the depth of eliciting and representing the problem situation according to a 5-point expert scale (1 is the lowest, 5 is the highest)

6 *Variety of labels* – how many different types of labels (descriptive, structural causal, interrogative and metaphorical) are used

7 *Flexibility of labels* – the extent to which the students reflect the complexity of situation through these labels – expert judgment on a 5-point scale (1 is the lowest, 5 is the highest)

8 *Divergence* – the extent to which the ideas are elicited, reflected, represented and created

9 *Number of ideas* – the number of all ideas generated

10 *Diversity of ideas* – an expert assessment on a 5-point scale (1 is the lowest, 5 is the highest)

11 *Originality of ideas* – an expert evaluation on a 5-point scale (1 is the lowest, 5 is the highest).

The scoring schema originally included the criteria of convergence and planning as well. They are excluded from the analysis in this study because convergence and planning were supported by graphical techniques different than concept maps.

The hypothesis related to mapping production predicts that the experimental group will score significantly higher than the control group on the various indicators of the criteria of broad perception such as *variety of nodes, flexibility of nodes, variety of labels and flexibility of labels*. The experimental group will score significantly higher than the control group on the divergence criteria's indicators such as *number of ideas, diversity of ideas and originality of ideas*.

A strong positive relationship is expected between the map production and the solution of the case. A relationship is assumed to exist between the scores on broad perception and divergence.

A set of assumptions is related to the perceived effectiveness of problem solving, which is measured by the reflections of the experimental subjects on the problem-solving method implemented in the concept mapping software they used. The participants in the experimental group will score significantly higher than the control group's participants on the *knowledge elicitation, knowledge creation and knowledge reflection* sub-scales of the post-session reflective questionnaire.

6.1 Subjects

The experimental subjects were selected through a sequential sampling (Krathwohl, 1993). We started with a small group of participants and continued until 47 students were assembled – the maximum number of participants we were able to convince to take part in the research.

6.2 Procedure

The students were randomly assigned to the control group and the experimental group. The experimental group was shortly introduced to SMILE Maker and the graphical editor implemented in it. The control group was introduced to Inspiration and its graphical editor. An ill-structured case was presented ('George Career Dilemma'). The students from both the control and the experimental groups were asked to solve this case individually, using the concept mapping tools they were assigned to. All students were asked to fill out a reflective questionnaire at the end of the session.

6.3 Instruments

The reflective questionnaire is aimed at collecting the experience of the participants with the concept mapping software in terms of problem-solving method, learning environment and interface of the tools. In this study only the results related to the method are reported. The *method* scale in the reflective questionnaire contains statements that describe types of behaviour indicative for knowledge elicitation, knowledge representation, knowledge reflection and knowledge creation. The reliability coefficient of the reflective questionnaire reached the value of .88 (Cronbach alpha) when tested with 32 students.

7 Results

7.1 Instructional support and problem solution

This study confirmed the hypothesis that the experimental group scored significantly higher (accepted significance level of .05) – $F(1, 45) = 5.897$, $p = .019$, than the control group on an expert criterion for a successful solution. Table 1 presents the mean figures related to this result.

Table 1 Mean scores of solutions of the problem

Solutions of a case	*M*		*SD*	
	Inspiration	SMILE	Inspiration	SMILE
	5.5	7.4**	2	3

Note: $N = 47$ (Inspiration: $n = 21$; SMILE: $n = 26$).
**$p < .05$.

The SMILE Maker group benefited from the systematic approach for problem solving based on the combination of cognitive mapping and creative problem-solving techniques.

Some data related to the mapping production contribute to the explanation of this result, although not all of them were at significant level.

7.2 Instructional support and mapping production

The experimental group showed better results than the control group on the indicator *variety of nodes*, but not at significant level – $F(1, 45) = 3.715$, $p = .06$. Table 2 presents the mean figures of the effect of the instrumental support on the indicators of *broad perception*. A significant difference in favour of the SMILE Maker group on the criterion *flexibility of nodes* was found – $F(1, 45) = 5.442$, $p = .024$. The experimental group is significantly better than the control group on the indicator *variety of labels* – $F(1, 45) = 6.002$, $p = .018$. On the indicator *flexibility of labels* a difference very close to significant was found – $F(1, 45) = 4.030$, $p = .051$. The use of SMILE Maker supports broad and deep perception of the problem situation. Different types of problem-solving representations (objective and subjective) and a variety of relationships (descriptive, structural, causal and metaphorical) reveal the complexity of problem situations. The instrumental support provided by SMILE Maker makes the perception of the problem situation more comprehensive, which leads to improvement of the problem-solving reasoning.

No significant difference was found, as it was expected, on the indicator *total number of nodes* – $F(1, 45) = 2.861$, $p = .098$. Inspiration software supports implicitly free association. In contrast to what was expected, however, the SMILE Maker group showed significantly better results than the Inspiration group on the indicator *fluency of nodes* – $F(1, 45) = 8.830$, $p = .005$. The score of the experimental group on the indicator *number of ideas* is higher, but not at significance level – $F(1, 45) = 3.680$, $p = .061$. Table 3 presents the mean values of the indicators for divergence criteria. The SMILE Maker group achieved better results, near to significant, on the indicator *diversity of ideas* – $F(1, 45) = 3.953$, $p = .053$. The tool produced significantly better results on *originality of ideas* – $F(1, 45) = 4.359$, $p = .042$. The data show that both tools equally stimulate the generation of many and diverse ideas. The explicit support based on a combination of some creative problem-solving techniques and concept mapping in SMILE Maker leads to more original ideas.

Table 2 Mean figures of the broad perception indicators

Broad Perception	*M*		*SD*	
	Inspiration	SMILE	Inspiration	SMILE
Number of nodes	14	17.5*	7	7
Fluency of nodes	2.2	3**	1	.9
Variety of nodes	3	3.7*	1.3	1
Flexibility of nodes	2.3	3.1**	1.2	1.1
Variety of labels	2	2.4**	.7	.6
Flexibility of labels	1.3	2*	.9	1.3

Note: $N = 47$ (Inspiration: $n = 21$; SMILE: $n = 26$).
*$p < .10$; **$p < .05$.

Table 3 Mean figures of divergence

Divergence	*M*		*SD*	
	Inspiration	SMILE	Inspiration	SMILE
Number of ideas	4.1	7.5*	4.9	6.6
Diversity of ideas	1.9	2.8*	1.6	1.6
Originality of ideas	1.4	2.3**	1.4	1.5

Note: $N = 47$ (Inspiration: $n = 21$; SMILE: $n = 26$).
*$p < .10$; **$p < .05$.

7.3 Relationships between problem solution, broad perception and divergence

The data confirmed a strong positive relationship between the final solution of the case and the criteria of broad perception and divergence. The higher the score on broad perception and divergence, the higher the score on the final solution. Table 4 presents the correlations between the score on the final solution and different indicators of broad perception and divergence. There is a significant positive correlation between the final solution and the following indicators of broad perception: total number of nodes, fluency of nodes, flexibility of nodes and flexibility of labels. There is a significant positive correlation between the final solution and all indicators of divergence: total number of generated ideas, diversity of ideas and originality of ideas. The variety of nodes and the variety of labels are not directly related to the final solution. The significance of the correlation between the score on solving the case and most of the indicators of the map production suggests a strong and direct relationship between solving of ill-structured problems and how broad and deep is the perception of a problem situation, and how fluent and flexible is the generation of ideas.

Table 4 Correlations between final solution and mapping production

Indicators	*Final solution*
Number of nodes	.358**
Fluency of nodes	.636**
Variety of nodes	.191
Flexibility of nodes	.603**
Variety of labels	.176
Flexibility of labels	.598**
Number of ideas	.612**
Diversity of ideas	.778**
Originality of ideas	.753**

**$p < .05$.

7.4 Relationships between broad perception and divergence

The study found positive correlations between most of the scores on broad perception and divergence (see Table 5). There was strong positive correlation between fluency of nodes, from one side, and number of ideas, diversity of ideas and originality of ideas, from another. There was a significant positive correlation between flexibility of nodes and diversity of ideas. A significant positive correlation was found between flexibility of labels, from one side, and number of ideas, diversity of ideas and originality of ideas, from another. The strong relationship between these indicators of broad perception and divergence confirmed the assumption for the existence of a connection between the extent to which the complexity of problem situation is adequately represented and the number and the originality of ideas. However, some of the results appeared not to be in line with the assumption relating broad perception and divergence. No significance was found for the following relationships: number of nodes and number of ideas, and diversity of ideas and originality of ideas. The number of information items in map information collection has no relationship with the diversity and originality of the ideas in map idea generation. What matters are the types of information items and the types of connections (labels) between them, not the number of nodes. Some studies on problem solving found that a greater number of information items do not necessarily lead to formulation of more original ideas (Kirton, 2003).

Although very close, there was not significant correlation (p = .051) between flexibility of nodes and number of ideas, and flexibility of nodes and originality of ideas.

A probable explanation is that students in the experimental group applied only one or maximum two of the proposed techniques for idea generation. Specifically, they did not use the technique that explores the use of variety of nodes. The same explanation could be applied to the existence of positive, but not significant, correlation between variety of labels and originality of ideas and diversity of ideas. The students in the experimental group did not use the problem-solving technique that is based on the variety of labels. The techniques for idea generation were too many for one experimental session and the students chose only one or maximum two of them, a fact that affected the production of ideas.

Table 5 Correlations between broad perception and divergence

Indicators	*Number of ideas*	*Diversity of ideas*	*Originality of ideas*
Number of nodes	.234	.181	.004
Fluency of nodes	.560**	.520**	.419**
Flexibility of nodes	.286*	.351**	.240
Variety of labels	.259*	.260*	.251*
Flexibility of labels	.559**	.670**	.712**

Note: $N = 47$ (Inspiration: $n = 21$; SMILE: $n = 26$).
*$p < .10$; **$p < .05$.

7.5 Perceived effectiveness of instrumental support for cognitive mapping

A number of assumptions are related to the scores of the participants on the items in the *method* scale of the reflective questionnaire. The score of the SMILE Maker group on *knowledge creation* sub-scale was significantly higher than the Inspiration group – $F(1, 45) = 4.730$, $p = .035$. The experimental group was superior to the control group when the scores on the *knowledge reflection* items were compared – $F(1, 45) = 7.823$, $p = .008$. The experimental group was significantly better on the indicator *knowledge representation* – $F(1, 45) = 7.660$, $p = .008$. Although the SMILE Maker students scored higher than the students in the Inspiration group, there was not significant difference on the indicator *knowledge elicitation* – $F(1, 45) = 3.517$, $p = .067$. This result can be explained by two reasons. Firstly, 'free association', which is a knowledge-elicitation technique, is embedded in the graphical functionality of Inspiration. The SMILE problem-solving method proposes several techniques for knowledge elicitation but the experimental subjects had time only to look at one or two of them. The first technique the tool suggests is 'free association', which is the same as in Inspiration, and the students in the experimental group applied it first. The difference in favour of SMILE Maker, although not significant, is due to the explicit support that the tool provides. Secondly, the interface of the Inspiration is quite attractive for supporting elicitation of information items and it contributes strongly to the positive perception of the participants in the control group.

The results related to the perceived effectiveness of the concept mapping tools should be checked against the indicators of the observable effectiveness in the map production. Indicators such as fluency of nodes, flexibility of nodes and diversity of ideas are an operationalisation of the concept of knowledge elicitation. SMILE Maker proved to be a significantly better tool for fluency of nodes ($p = .05$) and flexibility of nodes (*p* = .24). The significant difference for knowledge creation was expected because SMILE Maker offers techniques that combine the strengths of concept mapping and creative problem solving. The value of diversity of ideas was very close to significance (*p* = .53).

The significance in favour of the SMILE Maker group on knowledge reflection and knowledge representation was not expected because the graphical editor of Inspiration proposed support for both the functions. The difference could be attributed to the specific types of support for knowledge representation in SMILE Maker. The tool explicitly supports a variety of problem-solving representations and a variety of relationships between them. Another reason could be that knowledge representation, knowledge reflection, knowledge elicitation and knowledge creation are mutually beneficial to each other. Each of them amplifies the effect of others. See Table 6 for the relationships between knowledge representation, elicitation, reflection and creation.

Table 6 Correlations between elicitation, creation, reflection and representation

	Creation	*Reflection*	*Representation*
Elicitation	517**	410**	212
Creation		845**	159
Reflection			127

Note: $N = 47$ (Inspiration: $n = 21$; SMILE: $n = 26$).
**$p < .05$.

The data show high positive correlations between scores on knowledge elicitation and knowledge creation; knowledge reflection and knowledge creation and knowledge elicitation and knowledge reflection. Knowledge representation was not related in a significant way to knowledge elicitation, reflection and creation. Whereas knowledge representation is supported by an instruction related to the graphical functions of the cognitive mapping tools, knowledge elicitation, knowledge reflection and knowledge creation are supported by an instruction related to the problem-solving process and techniques. Knowledge elicitation, knowledge representation, knowledge reflection and knowledge creation are the main characteristics of a hypothetical construct assumed to explain how and why the instrumental support makes the cognitive mapping tools effective problem-solving tools.

8 Conclusion and discussion

The study confirmed most of the predictions on the effect of different types of instrumental support on problem-solving performance. The instrumental support for problem solving through concept mapping implemented in SMILE Maker proposes an operational framework consisting of several phases. Within each of them, support is provided including specific techniques for information collection, idea generation, idea selection and idea implementation. Successful problem solving is a function of how broad and deep the problem space is perceived, how fluent are the divergent activities, how adequate is the convergence of ideas and how comprehensive and feasible is the implementation of solutions. It is also important to identify the operational mechanism that makes this approach really workable. The instrumental support for problem solving through concept mapping provides instructional interventions including specific techniques that activate cognitive processes and structures specific for ill-structured problem solving such as knowledge elicitation, knowledge reflection, knowledge representation and knowledge creation. SMILE Maker supports eliciting of appropriate knowledge, overcoming the negative problem-solving effects such as functional fixedness, problem set, routine expertise and reproductive thinking, all being instantiations of the restricting part of the 'paradox of knowledge structure'. The 'paradox of knowledge structure' states that knowledge structure both enables and restricts successful problem solving in ill-structured problem situations. Knowledge structures are indispensable for ill-structured problem solving, but they could also be detrimental. Knowledge structure allows problem-solvers to look at the information in a meaningful way, but it may prevent them to look at the information in a new way. The problem-solving method in SMILE Maker is an effective way of managing the restricting part of the 'paradox of knowledge structure'. The problem-solving method of the tool helps retrieving not only the dominant thinking patterns but also all patterns that could contribute to solving a problem. SMILE Maker stimulates generation of as many and diverse ideas as possible (see the results related to fluency of nodes and flexibility of nodes), applying the principle 'quantity breads quality' (Nickerson, 2003). The instrumental support in SMILE Maker manages the complexity of the problem situation through different types of problem-solving items (facts, feelings, intuitions, metaphors) and variety of relationships between them – descriptive, structural, causal, metaphorical links (see the results related to variety of nodes, flexibility of nodes, variety of labels and flexibility of labels). Concept mapping is recognised as an adequate, accurate and flexible way of expressing how human mind organises incoming information (Stoyanov, 2001; Stoyanov and Kommers, 2006). Concept maps are external modes of representation, reflecting the internal cognitive processes and structures. SMILE Maker uses a simple and intuitive graphical convention that makes possible the adequate representation of complex relationships between ideas. The externalisation of internal problem-solving models extends the limited potential of working memory, thus reducing the cognitive overload. In addition, the externalisation of mental structures involves directly perception, which makes memory and thinking processes more effective. In this way, the method simulates *reflection in* the process of problem solving and *reflection on* the results of problem solving (see the results related to the relationships between the final solution of the problem and the criteria of broad perception and divergence). The reflection could result in some changes in the organisation of the problem-solving space, provoking creation of new configurations of knowledge. It is also easy with the software to manipulate the nodes. The SMILE Maker problem-solving method offers some techniques, which are synergy between concept mapping and problem solving to support *creation* of alternative solutions (see the results related to perceived effectiveness of instrumental support for concept mapping)

The strong positive correlation between knowledge elicitation, knowledge reflection and knowledge creation is the evidence that these characteristics are closely related to each other. It also should be expected that the good job done during map production can be a strong predictor for the successful solution of the problem. The higher the scores on broad perception and divergence, the higher the final result in solving the case. The broader and deeper the exploration of the problem situation, the higher the number of the original ideas generated.

This study identified some issues that need to be addressed in future research: (a) determining the potential of cognitive mapping for reducing cognitive load and (b) exploring the effect of individual problem-solving styles through cognitive mapping on problem-solving performance.

References

Buzan, T. and Buzan, B. (1996) *The Mind Map*, Plume, New York.

De Bono, E. (1990) *Lateral Thinking for Management*, Penguin Books, London.

Decision Explorer® [Computer software] (2003) Banxia Software, Kendal, Cumbria, UK.

Eden, C. and Ackerman, F. (2003) *Making Strategy: The Journey of Strategic Management*, Sage, London.

Guilford, J.P. (1967) *The Nature of Human Intelligence*, McGraw-Hill, New York.

Gulmans, J. (2004) 'Mapping for the constructivistic acquisition of concepts?', in Kommers, P. (Ed): *Cognitive Support for Learning*, IOS Press, Amsterdam, pp.31–45.

Hodgson, A. (1999) *Hexagons for Systems Thinking*. Available online at: http://www.orglearn.nl/Archives/Hexagons/hex1.rtft.html (accessed on 16 March 1999).

Huai, H. and Kommers, P. (2004) 'Cognitive styles and concept mapping', in Kommers, P. (Ed): *Cognitive Support for Learning*, IOS Press, Amsterdam, pp.209–228.

Idons-For-Thinking 2.0 [Computer software, demo version] (1999) Idon Software. Available online at: http://www.idonresources.com/demo.html (downloaded on 16 March 1999).

Inspiration® [Computer software] (2003) Inspiration Software, Inc., Beaverton Hillsdale, Portland.

Jonassen, D.H. (2004) *Learning to Solve Problems. An Instructional Design Guide*, Pffeifer, San Francisco, CA.

Jonassen, D., Reeves, T., Hong, H., Harvey, D. and Peters, K. (1998) 'Concept mapping as cognitive learning and assessment tools', *Journal of Interactive Learning Research*, Vol. 8 No. 3/4, pp.289–308.

Kennedy, D. and McNaught, C. (1998) 'Use of concept mapping in the design of learning tools for interactive multimedia', *Journal of Interactive Learning Research*, Vol. 8 No. 3 and 4, pp.389–406.

Kirton, M. (2003) *Adaption–Innovation: In the Context of Diversity and Change*, Routledge, London.

Krathwohl, D.R. (1993) *Methods of Educational and Social Science Research. An Integrated Approach*, Longman, New York.

MindManager® 4 [Computer software] (2003) Mindjet LLC, San Francisco, CA.

Nickerson, R. (2003) 'Enhancing creativity', in Sternberg, R. (Ed.): *Handbook of Creativity*, Cambridge University Press, New York, pp.392–430.

Novak, J.D. (1998) *Learning, Creating and Using Knowledge. Concept Maps™ as Facilitative Tools in Schools and Corporation*, Lawrence Erlbaum Associates, Mahwah NJ.

Novak, J.D. and Gowin, D.B. (1984) *Learning How to Learn*, Cambridge University Press, Cambridge.

Reimann, P. (1999) 'The role of external representations in distributed problem-solving', *Learning and Instruction*, Vol. 9, pp.411–418.

Sherry, L. and Trigg, M. (1996) 'Epistemic forms and epistemic games', *Educational Technology*, Vol. 36, No. 3, pp.38–44.

STELLA 7.0 [Computer software, demo version] (2000) High Performance System, Inc., The System Thinking Company. Available online at: http://www.hps-inc.com (downloaded on 19 November 2000).

Stoyanov, S. (2001) *Mapping in the Educational and Training Design*, Doctoral dissertation, University of Twente, the Netherlands (Print Partners Ipskamp, Enschede).

Stoyanov, S. and Kommers, P. (2006) 'WWW-intensive concept mapping for metacognition in solving ill-structured problems', *International Journal of Continuing Engineering Education and Lifelong Learning*, Vol. 16, No. 3 and 4, pp.297–316.

Vennix, J. (1997) *Group Model Building. Facilitating Team Learning Using System Dynamics*, John Wiley & Sons, Chichester.