Concept Mapping: A Process-Tool for Understanding Design and Customer Requirements

Greg Michalski
R&D Effectiveness, Information & Learning Products & Services (8I53)
135 SKY, ESN 393-3736

Keywords: war room, knowledge dissemination & utilization, group process, organizational learning

Abstract

Concept mapping is a structured group process and tool (process-tool) for complex and/or strategic planning and evaluation. Recent trials at Nortel Technology provide evidence of a potential for expanded use of concept mapping technology as a means to better understand a wide range of design and customer requirements.

This paper has four main purposes: (1) to introduce a process and procedure of concept mapping, (2) to offer application examples for illustration, (3) to relate the use of concept mapping with organizational learning, and (4) to highlight how concept mapping might be used in a broad range of settings throughout the design community.

A high-level overview of a concept mapping process based on the use of the Concept System is presented. The Concept System is a commercially available software application that has been optimized to perform the advanced statistical calculations required for the construction of the concept maps as analytical aids.

Specific examples discussed here include the definition of requirements for a virtual war room (Michalski, 1996a) and, applications for training program planning, development, and evaluation metric construction (Michalski, 1996b, c).

Use of concept mapping is also shown to contribute to the process of organizational learning. Several such implications based on principles of cognitive learning theory, knowledge construction, dissemination, and utilization are discussed.

You are encouraged to consider innovative applications for concept mapping to tap the individual and collective expertise and experience of your group particularly to more effectively meet design and customer requirements.

Introduction

The importance of individual and collective learning as a source of strategic organizational advantage is well recognized (Senge, 1990; Huber, 1991; Hammer & Champy 1993, Gale, 1994, Pepitone, 1995). A growing number of authors describe the critical role of such learning specifically in R&D organizations (Friedman, 1992, Pisano, 1994). Yet specific processes and methods to foster the development and application of group learning remain elusive. In an environment occupied by dense interpersonal networks of highly skilled and educated knowledge workers, it seems reasonable to continuously seek improved ways to generate, synthesize, share, and use new knowledge locally from within the work or project group. Among the many ways this can and does happen (casual conversations, shop-talk, team meetings, lunchtime learning, presentations, etc.), a more structured (less ad hoc) complementary method can help. The concept mapping process effectively captures both individual and group expertise to promote dialog and develop local knowledge for action.

Concept Mapping: An Overview

Background: According to Michelin (1995) the precursors of a general concept mapping process can be traced back in several disciplines. One of these is Ausubel's (1968) work in cognitive theory. Since then numerous discussions of differing kinds of concept mapping are described in the literature. These range from the mostly *qualitative* (Novak, 1990; Rafferty & Fleschner, 1993; Reader & Hammond, 1994) to more *quantitative* approaches. The discussion here assumes specific use of the later (more quantitative) approach using the Concept System. Developed largely through the continuing work of Dr. William Trochim at Cornell University, this application is optimized to perform the advanced statistical calculations (multidimensional scaling and hierarchical cluster analysis) required to produce the physical concept maps for use in planning, evaluation, and decision support particularly in contexts of high complexity or uncertainty.

Process Description: In the simplest sense the concept mapping process involves a group wishing to collaboratively problem solve. The process consists of six steps: (1) assembling the participants and focusing the problem statement, (2) brainstorming solution statements, characteristics, or attributes, (3) structuring the statements, (4) generating and displaying the concept maps, (5) interpreting the maps, (6) using the results. The total process moves from the *group* (steps 1 and 2), to the *individual* (step 3), and back to *group* (steps 4 through 6). Depending on the number of participants and the complexity of the problem, a concept mapping session could require anywhere from 2 hours to a full-day or more. The "running time" of the session does not have to be continuous and can be spread out over a reasonable time period. Further, while a physical assembly of participants is desirable, the process can be administered remotely (using audio/video meetings, for example).

Steps 1 and 2 are simply a brainstorming session using the typically suggested rules for group brainstorming (definition of the brainstorm problem statement, open format, no judgements, "anything" goes, etc.). The product at the end of step 2 is a numbered list of solution statements generated by the group. In preparation for the individual statement structuring task (step 3) each statement is printed on a card, one statement per card. The structuring of the statements by individuals consists of two subtasks, card (statement) *sorting*, and statement *importance rating*.

The rules for sorting are straightforward:

1. On a large surface, lay all the cards out so each is readable; 2. Scan the statements on the cards. *Sort the cards in a way that makes sense to you*. Place similar statements together in the same pile. Group by similarity, not priority; 3. (assuming a total of n statements) You may have as many piles as you wish—except you cannot have only one pile (of n) or n piles (of one). If you believe, however, that a statement is unrelated to all of the others, you may place it in its own pile. There are no right or wrong groupings. You may name the piles (groupings) if you wish by writing the name you choose on the back of the top card; 4. After you have sorted and grouped all cards, please secure each pile with a paper clip. Stack the clipped piles into one stack and secure this with a rubber band. Submit this to the facilitator.

Each individual also rates the importance of each statement using the following instructions:

Using the "importance rating form," rate each of the n statements in accordance to their importance. By writing a number on the blank line in front of each statement, rate each using a 1 to 5 scale (where 1=relatively unimportant and 5=extremely important). You are encouraged to spread your ratings out by using all five rating values at least once. Submit your completed rating form to the facilitator.

The individually sorted and rated statements constitute the raw data for computation of the visual concept maps. The final list of brainstormed statements describe the *conceptual domain* for the session focus. As discussed in the "statistical processing overview" section of this paper, most of the computation performed relates to representing this domain as a visual map in two dimensions. The importance rating data is then added to produce a third dimension (relief) map showing distinct groupings (clusters) of concepts also ranked in importance.

Tool Description: During the session, all statements are entered into the Concept System (program) using a PC. Using a video projection device (LCD/overhead projector, video projector, etc.) the statements can be displayed to the group for reference and editing. the Concept System also handles the production of statement sorting cards and rating sheets (using a printer).

The real power of the Concept System lies in its optimization for the statistical processing of sorting and rating data to easily produce visual concept maps. While these calculations could be done using any number of commercially available (general) statistics packages (for example, SPSS or SAS) the Concept System integrates and simplifies both facilitation and analysis.

Statistical Processing Overview: The emphasis of the Concept System software is the production of the maps used for discussion by the group. The main goal of a concept mapping session is to more completely describe the topic at hand to allow for better group understanding using a process of discussion and dialog. The software simply facilitates this process. The following brief discussion of the calculations performed is not intended to delve into their statistical details, but rather to give some sense of how the raw sorting and rating data are transformed into visual maps.

As mentioned most of the computation involves transforming the sorting data into a two-dimensional representation or *point map*. A point map shows each statement as a numbered point arranged in two dimensions. To begin, a two-dimensional *binary symmetric similarity matrix* consisting of as many rows and columns as there are statements (n rows and columns) is constructed for each individual. A binary "1" in any cell of this matrix indicates the individual has sorted two statements into the same pile. This matrix is calculated for each individual's sortings. Next, the individual matrices are added together to form the *final group similarity matrix*. This indicates the number of people who placed any pair of statements together in a pile and provides the *relational structure* of the conceptual domain. A high value in any cell of this matrix indicates that many participants placed a pair of statements together in a pile and implies that the statements are conceptually similar in some way.

Next, a two-dimensional non-metric multidimensional scaling is performed on the final group similarity matrix. Non-metric multidimensional scaling is a multivariate statistical technique to transform a proximity matrix into any number of distances between the original items (points) in the matrix. Using two dimensions, this essentially places statements that were sorted together more often in close proximity on a plane opposite to statements sorted together less often. The product of this procedure is the point map.

Using the point map a final computation is performed to group and isolate closely located points (statements). This is done by a hierarchical cluster analysis (using Ward's algorithm). The default number of clusters produced is set to one-fifth the total number of statements, although this can (and usually must) be adjusted to the satisfaction of the group. In essence, the software provides a *baseline* starting point. Substantial input from the group is required for closure.

The computations described so far used only sorting data. In fact, two dimensional concept maps can be produced without any importance rating data at all. Importance rating data is processed separately and then added to introduce (three-dimensional) relief to the point and cluster maps (it should be noted that there is not a single definitive concept map but a series of interrelated point and cluster concept maps). Average item and cluster importances are calculated using the arithmetic mean of 5-point (*Likert-type*) scale responses.

Without going into any more detail here, it should be recognized that the key objective of all this calculation is to *fairly and systematically* represent how the group conceptualizes the problem for solution. For a more detailed explanation please feel free to contact me directly. For a printed reference (discussion of methodological and measurement issues) see Trochim (1989).

Nortel Technology Examples

This section summarizes the results of concept mapping use at Nortel Technology. Two examples are briefly described here include *A Concept Mapping Definition of A Virtual War Room Information Navigation System* (Michalski, 1996a) and *A Concept Map of Knowledge and Skill Requirements for Newly Promoted Managers* (Michalski, 1996b). These are provided to illustrate the practical aspects of concept mapping use.

Virtual War Room Definition

A "virtual" war room is an online (computerized) version of a physical war room. The definition of a "war room" dates back at least to 1914 as "a room at a military headquarters where maps showing the current status of troops in battle are maintained." (Webster's, 10th). Gale (1994) extended this to the modern business organization. In connection with the process of *customer value management*, he described the war room as a means of "putting the power of your whole organization in a single room." (p. 241) Like the original war room, the main intent is to create a highly usable tactical and strategic information display to assist decision making.

Transport Networks War Room Team: On October 5, 1995, a cross-functional team of twelve people participated in an all-day working session to explore the potential and define the main characteristics, features, and evaluation attributes of a virtual war room (VWR) for use at Nortel. Representing several North American labs and locations (RTP, RICH, STL, OTT) these people produced a brainstormed list of 66 statements in response to the focus question, *"What features and evaluation attributes should be considered in the design and implementation of a VWR system? "*

The 66 responses to this question varied tremendously from statements about "cost effectiveness" and "customer business focus" to "artificial intelligence" and "support for real-time benchmarking." This result seemed to underscore the reality that it is much easier to brainstorm solutions to any given focus statement in a group setting than it is to process the results in a way that is fair and representative of each individual's view. Yet this provided a prime example of an opportunity to apply concept mapping.

For logistical reasons, the sorting and rating tasks (structuring) of the 66 originally brainstormed were performed remotely by the October 5 group over the next 6-week period. This was done by sending each participant an interoffice mailing containing (a) the sorting cards (one statement per card) for the 66 statements, (b) a rating sheet with a 5-point scale of importance for each statement, and (c) a concise instruction sheet describing the sorting and rating tasks. A pre-addressed return envelope was also included for data return.

Of the twelve original participants, eight returned usable data. This was entered into the Concept System (v. 2.0) using a PC. The default cluster solution defined 12 distinct clusters (roughly one-fifth the number of original statements). These results were then presented at a subsequent war room team meeting (Dec. 13, in St. Laurent) for explanation, discussion, and cluster naming. After an individual and group process in which each individual was asked to produce a short name that seemed to generally describe the statements grouped in to each of the 12 clusters and then propose these for group discussion and consensus, the group eventually decided on the following cluster names: (1) effective, (2) friendly, (3) actionable, (4) data access/integrity, (5) intelligent (6) flexible, (7) training, (8) menu driven, (9) evolution, (10 performance, (11) alignment, (12) business focus. Based on their importance and the frequency with which each person sorted statements similarly (indicated by a low "bridging" index for an item or cluster), the following top characteristics emerged:

- Business Focus
- Training
- Friendly
- Alignment
- Data Access/Integrity

The "business focus" cluster showed the most similarity in how people sorted statements (lowest bridging index) and it had the second highest importance overall. It contained statements such as "answers business questions" and "support to globalization and international nature of business." In addition to the expected training on the mechanics of system use, the "training" cluster emphasized training aimed at creating the culture shift required to foster widespread VWR use, especially as *participative action learning* (see Gale, p. 356). The third most highly ranked cluster labeled simply as "friendly" by the group contained attributes emphasizing that the system be not only easy to use but even fun to use and personalized as well. The "alignment" cluster contains statements indicating that the system should support alignment and harmonization of business strategy in terms of Nortel Core Values, market, and customer requirements. Finally, "data access/

integrity" is fairly self-explanatory highlighting the need for the system to contain accessible, accurate information.

These results were used to support the commercial specification and business case to proceed on the war room project. While space limitations limit further discussion here, a more detailed description of these result is contained in Michalski (1996a). That paper lists all statements along with bridging and rating results and presents the point and cluster maps discussed.

New Manager Knowledge and Skill

A second example of concept mapping concentrates on the improvement of management training by the Transmission Training Group for Division 1 of Nortel Technology.

The following brief description summarizes the results of a concept mapping session held January 11, 1996 for a group of "new D-level" managers in response to the question, *"In your view, what skills and knowledge are required to enable you to perform your job as a manager effectively?"* In response to this question eight newly promoted or assigned (within the last 6 months to 1 year) generated a total of 64 short statements that produced a 12 cluster default solution. The number of clusters was later adjusted to 9 with the following labels: (1) Mac use for project planning, (2) administrative tools, task prioritization, and customer, (3) technical customer application (requirements) and future trends, (4) management and organizational expectations, (5) administrative process and procedure, (6) career development and MFA, (7) team building and people development, (8) 360-degree communication and leadership, (9) time management and effectiveness. The three top clusters (assigned the highest importance) were team building and people development (3.96/5), career development and MFA (3.80), and 360-degree communication and leadership (3.80). The way in which the new managers sorted the statements into similar piles is also revealing as reflected by an extremely low bridging value (0.03) for the most highly rated (importance) cluster related to team building and people development. Bridging is an index value with a range of 0 to 1. As mentioned, a low bridging value for a cluster or statement indicates that people tended to sort statements together in a similar way. As mentioned in the summary report these findings should be viewed as part of an emerging set of results useful for discussion and planning to be used in conjunction with other program improvement data (surveys, discussion groups, etc.) ultimately aimed at creating substantive improvements to the Transmission Management Training Track. For further details see Michalski and Spencer (1996b). That paper lists all statements along with quantitative data as well as the final concept map.

Relationships to Organizational Learning

Definition and Literature: The October 5 VWR design session was preceded by several preparatory presentations within the Transport Networks group. One of these presentations addressed the topic of organizational leaning (Michalski, 1995).

Founded on several earlier discussions of organizational decision making or learning cycles (Cyert & March, 1963; March & Olsen, 1976), the current literature on organizational learning is burgeoning indeed. The now well known work of Peter Senge (1990) has served for many as an introduction to a truly broad literature that spans several diverse fields and disciplines including organizational theory, business administration and management, psychology, leadership, and education (training and development) to name just a few. Of the many definitions proposed (Argyris & Schon, 1978; Hedberg, 1981; Fiol & Lyles, 1985, Argyris, 1993), Dixon offers Duncan & Weiss's (1979, p. 84) definition "Organizational learning is defined as the process by which knowledge about action outcome relationships between the organization and the environment is developed." Most syntheses on organizational learning (Huber, 1991) support that organizational learning is a collaborative process equal to more than the sum of individual learning. Senge (1990) and others have emphasized the absolute imperative that organizations either become adept in learning at the collaborative (systems) level or face competitive extinction. If this is true in general for any given organization, it seems particularly so for those heavily dependent on R&D and technological innovation.

Linkages to Concept Mapping: The linkages between the use of the concept mapping and processes of organizational learning are unmistakable. Louis (1995) stated that *organizational learning begins with a social constructivist perspective...knowledge is not usable at the local site until it has been "socially processed" through some collective discussion and agreement of its validity and applicability* (p. 13). While this local processing can and does occur on an ad hoc basis (as an important component of any local organizational or project team "culture"), the concept mapping process-tool explicitly, systematically, and fairly focuses, develops, and documents it. In this sense the process of concept mapping helps individuals think as a group without losing their individuality.

Many other such linkages can be drawn between the concept mapping process and learning at the organizational level within organizations. For example, Cousins and Leithwood (1993) have described a conceptual framework for knowledge utilization that places the use of knowledge on a continuum described by learning at one extreme (educative utilization) and decision making at the other extreme (instrumental utilization). A case can be made that concept mapping potentially assists at any point along this continuum. Other such linkages include the use of concept mapping to foster the *acquisition*, *distribution*, and *interpretation* of information; local *sensemaking*; ability to tap *organizational memory*. Finally, based on its emphasis on the application of knowledge to relevant problems, use of the method also seems to be supported by principles of adult learning, or *andragogy*, as discussed by, for example, by Knowles (1990).

Design and Customer Requirements

Once understood, the potential applications for concept mapping seem unlimited. The process can be used to obtain far more structured and fair results than can be obtained in a typical focus session or general meeting. The method also offers a refreshing alternative to the (all too ubiquitous) customer survey questionnaire for data collection. While such surveys have been seen to be increasingly overused (and even abused) for organizational data collection (Swanson & Zuber, 1996) these still have their place. As suggested at the beginning of this paper, you (the reader) are the best judge of how concept mapping might be applied for collective problem solving. Potential uses to understand customer requirements can best be obtained by involving customers in a concept mapping session. If, for example, these requirements involve the description of a high-level design, designers should join the session. Obviously, once a project is specified and the "dirty work" begins concept mapping would take a back seat to the tactical details of project management and execution.

Position

Concept mapping is a useful process-tool for certain problems and contexts. It has been successfully used here at Nortel Technology as described in the examples stated. It seems likely that others in the organization might benefit in learning more about and using this group technology. Particularly relevant might be applications that require high levels of individual expertise focused in a group planning, evaluation, or problem solving context. Specific examples at Nortel might include advanced product planning and design (tier 2, tier 3 project planning), evaluation systems design, and as a means to develop understanding of customer requirements across technical disciplines.

Observations and Comparisons

Concept mapping has and is being used in a wide variety of settings where group input is required. The literature cited in this paper further describes some of these. In addition to the Concept System mentioned here, it should be noted that many other alternatives exist. These included both the qualitative and (other) quantitative options mentioned earlier. Currently several large consulting firms offer concept mapping as a service to clients. Whether ultimately choosing such a firm to facilitate a session, or capitalizing on the internal expertise and capability within your group or organization, it is strongly recommended that participants spend some time to become familiar with the basics of the concept mapping technology. Since a main point of concept mapping is to develop understanding from *within the group*, it seems only reasonable to develop the flexibility to self-administer the process (similarly) from within on an as-needed basis.

Conclusion

It is my hope that this document has given you some sense of how concept mapping might be used to assist your work. But the question may arise, "Is concept mapping merely a fad destined to pass into corporate history?" Maybe. However, sufficient background research has been done, and sufficient numbers of intelligent individuals within complex organizations have embraced the technology that, given even a reasonable doubt, it seems worth a try. Perhaps the frequency of use of a technology such as concept mapping depends on your own field of interest. For example, it is known that certain sectors seem to have embraced concept mapping already. These include for example, the broad field of human services, education, business planning, evaluation, etc. Yet there seems to be plenty of room left for others.

One of the most promising areas of application is to construct evaluation models. The use of concept mapping is currently being proposed as a means to construct a highly usable model for the evaluation of training effectiveness at the program level.

While page limitations restrict further discussion here, you are encouraged to obtain and review some of the references cited. Because a number of these may not be available on a widespread basis, I would be glad to send you a copy of the *unpublished or proprietary* works cited. Also, please feel free to contact me to follow up on or discuss any aspect of this paper.

References

[Argyris93] C. Argyris, "Knowledge for Action. San Francisco: Jossey-Bass.

[Argyris78] C. Argyris and D. Schon, "Organizational Learning; A Theory of Action Perspective" Reading, MA: Addison-Wesley.

[Ausubel68] David P. Ausubel, "Meaningful Reception Learning and the Acquisition of Concepts" In H. J. Klausmeier and C. W. Harris (Eds.) Analyses of Concept Learning, pp. 157-175.

[Cousins93] J. Bradley Cousins and Kenneth A. Leithwood, "Enhancing Knowledge Utilization as a Strategy for School Improvement, Knowledge: Creation, Diffusion, Utilization, Vol. 14, No. 3, pp. 305-333.

[Cyert63] R. Cyert and J. March, "A Behavioral Theory of the Firm" Englewood Cliffs, NJ: Prentice Hall.

References (continued)

[Duncan79] R. Duncan and A. Weiss, "Organizational Learning: Implications for Organizational Design" Research in Organizational Behavior, Vol. 1, 75-123

[Fiol85] C.M. Fiol and M.A. Lyles, "Organizational Learning. Academy of Management Review" Vol. 10, No. 4, pp. 803-814.

[Friedman92] Lee Friedman, Edwin A. Fleishmann, and Jennifer Mikulka Fletcher, "Cognitive and Interpersonal Abilities Related to the Primary Activities of R&D Managers" Journal of Engineering and Technology Management, Vol. 9, pp. 211-242.

[Gale94] Bradley T. Gale, "Managing Customer Value" New York: The Free Press.

[Hammer93] M. Hammer and M. Champy, "Reengineering the Corporation: A Manifesto for Business Revolution" New York: HarperBusiness.

[Hedberg81] Bo Hedberg, "How Organizations Learn and Unlearn" In P.C. Nystron, & W.H. Starbuck (Eds.) Handbook of Organizational Design: Vol. 1, Oxford University Press.

[Huber91] George P. Huber, "Organizational Learning: The Contributing Processes and the Literatures" Organization Science, Vol. 2, No. 1, pp. 88-115.

[Knowles90] Malcolm Knowles, "The Adult Learner: A Neglected Species" Houston: Gulf.

[Louis95] Karen Seashore Louis, "Two Steps Forward, One Step Back: Do We Need a New Theory of Dissemination and Knowledge Utilization?" Paper presented at the symposium Dissemination and Utilization of Research Knowledge, Oslo, Norway.

[March76] J. March and J. Olsen, "Ambiguity and Choice in Organizations" Bergen, Norway: Universitetsforlaget.

[Michalski95] G.M. Michalski, "Organizational Learning: The Power and Challenge of Collective Knowledge Use" Presentation to the Transport Networks War Room Design Team, Ottawa, Oct. 3.

[Michalski96a] G.M. Michalski, "A Concept Mapping Definition of a Virtual War Room Information Navigation System" Ottawa: Nortel Technology, internal working draft, Jan96.

[Michalski96b] G.M. Michalski, M.J. Spencer "A Concept Map of Knowledge and Skill Requirements for Newly Promoted Managers" Ottawa: Nortel Technology. Transmission Training, internal report, Feb96.

[Michalski96c] G.M. Michalski, "Evaluating Training Effectiveness in Complex Organizations" Ottawa: University of Ottawa, unpublished manuscript, April.

[Michelin95] Linda Michelin, "Concept Mapping: Structured Conceptualizations in Evaluation" Ottawa: University of Ottawa, unpublished manuscript, April95.

[Novak90] "Concept Maps and Vee Diagrams: Two Metacognitive Tools to Facilitate Meaningful Learning" Instructional Science, 19, p. 29-52

[Pepitone95] James S. Pepitone, "Future Training" Dallas: AddVantage Learning Press.

[Pisano94] Gary P. Pisano, "Knowledge, Integration, and the Locus of Learning: An Empirical Analysis of Process Development" Strategic Management Journal, Vol. 15, pp. 85-100.

[Rafferty93] Cathleen D. Rafferty and Linda K. Fleschner, "Concept Mapping: A Viable Alternative to Objective and Essay Exams" Reading Research and Instruction, Vol. 32, No. 3, pp. 25-34

[Reader94] Will Reader and Nick Hammond, "Computer-Based Tools to Support Learning from Hypertext: Concept Mapping Tools and Beyond" Computers Educ., Vol. 22, No. 1/2, pp. 99-106

[Senge90] Peter M. Senge, "The Fifth Discipline: The Art and Practice of the Learning Organization" New York: Doubleday.

[Swanson96] Richard A. Swanson and John A. Zuber, "A Case Study of a Failed Organization Development Intervention Rooted in the Employee Survey Process" Performance Improvement Quarterly. Vol. 9, No. 2, pp. 42-56.

[Trochim89] William M. K. Trochim, "An Introduction to Concept Mapping for Planning and Evaluation" Evaluation and Program Planning, Vol. 12, pp. 1-16.

[Trochim93] William M. K. Trochim, "The Reliability of Concept Mapping" Cornell University, paper presented at the Annual Conference of the American Evaluation Association, Dallas, Nov. 6