Information Visualization (2006) 5, 202–210

www.palgrave-journals.com/ivs

A comparison between concept maps, mind maps, conceptual diagrams, and visual metaphors as complementary tools for knowledge construction and sharing

Martin J Eppler[1]

[1] *Faculty of Communication Sciences, University of Lugano (USI), Lugano, Switzerland*

Correspondence:
Martin J. Eppler, Faculty of Communication Sciences, University of Lugano (USI), Lugano, Switzerland.
Tel.: 058 666 45 12
Fax: 058 666 46 47.
E-mail: martin.eppler@lu.unisi.ch

Abstract
In this article, Novak's concept mapping technique is compared to three other types of visualization formats, namely mind maps, conceptual diagrams, and visual metaphors. The application parameters and the respective advantages and disadvantages of each format for learning and knowledge sharing are reviewed and discussed. It is argued that the combination of these four visualization types can play to the strength of each one. The article then provides real-life examples from such a use in undergraduate and graduate university teaching. The results provide first indications that the different visualization formats can be used in complementary ways to enhance motivation, attention, understanding and recall. The implications for a complementary use of these visualization formats in class room and meeting contexts are discussed and a future research agenda in this domain is articulated.
Information Visualization (2006) **5,** 202–210. doi:10.1057/palgrave.ivs.9500131

Keywords: Concept map; mind map; conceptual diagram; visual metaphor; concept skeleton; complementary visualization

Introduction: concept mapping and the realm of qualitative visualization methods

The extensive use of concept maps in class rooms and related learning and knowledge sharing contexts (e.g. trainings, meetings, problem solving discussions) has shown that numerous benefits can be achieved by applying visual mapping techniques that foster the graphic re-construction of knowledge (see Novak[1,2]). Concept maps have demonstrated their positive effects on student learning for various topics and in various teaching situations.[3] Concept maps (for a definition see Table 1) are, however, not without drawbacks [15–17] and they may not fit all types of *target groups* (such as non-academics), *learning tasks* (i.e. developing procedural skills), *application situations* (such as rapid note taking) or *topics* (such as processes or developments over time). There are, in our view, several reasons for these application restrictions: the relatively strict formal rules that need to be adhered to when drawing a concept map and the emphasis on *identifying concepts* (and their *multiple relationships*) do not make it a simple, seamless or very rapid visualization technique. In addition, the general *top-down* (from concepts to examples) *structure* of concept maps may not be adequate to represent or structure sequential content such as processes, timelines, or developments. The *boxes* and *arrows* format may also make it difficult to efficiently represent a great number of related items in an accessible format. Students or practitioners who are confronted with ready-made

Received: 8 February 2006
Revised: 31 March 2006
Accepted: 13 April 2006
Online publication date: 22 June 2006

Table 1 A comparison of concept maps, mind maps, conceptual diagrams, and visual metaphors

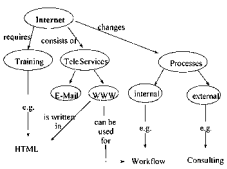
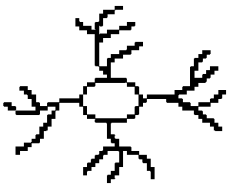
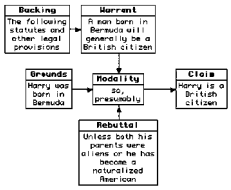
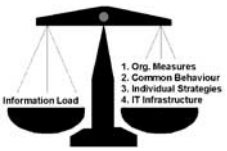
Format Parameters	*Concept map (J.D Novak)*	*Mind map (T. Buzan)*	*Conceptual diagram*	*Visual metaphor*
Sample thumbnail representation				
Definition	A concept map is a top-down diagram showing the relationships between concepts, including cross connections among concepts, and their manifestations (examples)	A mind map is a multi-coloured and image-centred, radial diagram that represents semantic or other connections between portions of learned material hierarchically	A conceptual diagram is a systematic depiction of an abstract concept in pre-defined category boxes with specified relationships, typically based on a theory or model	A visual metaphor is a graphic structure that uses the shape and elements of a familiar natural or man-made artefact or of an easily recognizable activity or story to organize content meaningfully and use the associations with the metaphor to convey additional meaning about the content
Main function or benefit	Shows systematic relationships among sub-concepts relating to one main concept	Show sub-topics of a domain in a creative and seamless manner	Analyze a topic or situation through a proven analytic framework	Organize content meaningfully and convey main message about it
Typical application context	Classroom teaching, self study and revision	Personal note taking and reviewing	Slide presentations, text illustration, management discussions	Text book illustration, summaries, presentations to novices
Application guidelines	Use it as a learning support tool for students, that is, to summarize key course topics or clarify the elements and examples of an abstract concept	Use it for pre-analytic idea jostles or rapid note-taking, or to structure the main contents of a course or topic hierarchically	Use it to structure a complex topic with the help of pre-defined categories	Use it to memorize the key elements of a method or concept by placing them meaningfully within a fitting graphic metaphor that shares one or more properties with the topic
Employed graphic elements	Boxes/bubbles with text and labelled connector arrows	Central topic bubble and colored (sub-) branches with text above branches, pictograms	Labelled boxes and arrows with embedded text (if needed: icons)	Text within visual structure, sometimes connected through arrows
Reading direction	Top-down	Center-out	Left to right or top to bottom	Bottom-up (e.g. ladder), top-down (funnel), in-out (wheel), out-in (spiral)
Core design rules or guidelines	Start with main concept (at the top), and end with examples (bottom, without circles); boxes/bubbles designate concepts, arrows represent relationships; include cross-links among elements	Start with main topic (center) and branch out to sub-topics, employ pictograms and colors to add additional meaning. Write text above the branches	Label all boxes. Fill all boxes with corresponding text. Larger boxes designate more important information	Employ a visual metaphor that has a strong and clear main association that is related to the conceptual domain that is mapped. Use a metaphor with clearly detectable areas.

Table 1 (Continued.)

Format Parameters	*Concept map (J.D. Novak)*	*Mind map (T. Buzan)*	*Conceptual diagram*	*Visual metaphor*
Macro structure adaptability	Flexible, but always branching out	Somewhat flexible, but always radial	Fixed diagram shape	Fixed metaphor shape (variations regarding elements)
Level of difficulty	Medium to high	Low	Medium to high	Low to medium
Extensibility	Limited	Open	Limited	Very Limited
Memorability	Low	Medium to high	Low to Medium	High
Understandability by others	High	Low	Medium	High
Typical software package supporting the visualization format	www.inspiration.com	www.mindmanager.com	www.visio.com	www.lets-focus.com

complex concept maps may initially feel overwhelmed or de-motivated by the complex web of relations.[16]

Concept mapping is also not the only available qualitative visualization technique that fosters learning or knowledge sharing in a constructive and systematic manner. There is a myriad of node-link mapping methods from such diverse areas as psychology, computer science, requirements engineering, or business administration. Examples of such systematic methods that employ geometric figures for items, activities or concepts, and arrows for relationships are: cognitive mapping, mind mapping, entity-relationship models, flow charts, Toulmin maps, IBIS argumentation maps, semantic networks, swim lane diagrams, clustering, UML diagrams, system dynamics, evocative knowledge maps, soft system modelling, or process event chains.[4–6,10–12,32] All of these methods relate (boxed, circled, or otherwise framed) items to others through (labelled or unlabelled) arrows based on explicit and sequential rules. Nevertheless, there are also mapping methods that do not make use of the node-link paradigm. Examples of such mapping methods are: Venn and Euler diagrams, Robert Horn's infomulas, radar charts, Zwicky's morphological boxes, Vee diagrams, knowledge cartographies, tree maps, 3D-cubes, S-curves, impact wheels, or graphic facilitation.[32,33] Rather than highlighting individual items and their relationships, these visualization methods focus on 'the big picture', that is, on an overall structure to map or position information meaningfully. In these methods, the overall graphic structure is usually provided by a conceptual diagram, a visual metaphor or a mix of the two.

Based on this premise, this paper examines the potential of *complementary visualization*[4] with regard to concept maps, that is to say the combination of concept maps with other visualization formats. This combined use of different visualization methods should compensate for the limitations of different individual mapping methods and enable a richer learning experience for students using the methods either actively (in a drawing mode) or passively (in a viewing mode).

Methods: systematic comparison along application parameters and exploratory use cases

The domain of visual methods for learning and knowledge sharing is a broad one and the diverse learning needs and styles of students may make it necessary to use concept maps only as one type of learning support tool among others. Hence, it seems worthwhile to review the application parameters and the relative advantages and disadvantages of concept maps, as they have been discussed in the existing literature, and compare them to the application benefits and parameters of other mapping methods. For this comparison, we have chosen one widely used method, mind mapping,[6] and two less prominent approaches, conceptual diagrams and visual or graphic metaphors. Below, we briefly describe our understanding of mapping approaches based on conceptual diagrams and visual metaphors.

A *conceptual diagram* [28] employs a graphic conceptual framework to visually structure information or learning content with the help of pre-defined categories. The categories are usually derived from a (domain-specific) theory or model. Examples of such conceptual diagrams are Aristotle's square of oppositions (visualized first by Boethius), Stephen Toulmin's argumentation diagram,[7] Michael Porter's five forces diagram,[8] Ishikawa's 5M diagram,[22] or Kaplan and Norton's strategy map.[9] All of these conceptual diagrams structure information visually with the help of pre-defined (often theory-derived) graphic 'containers'.

Visual metaphors [21,27] are graphic structures that use the shape and elements of a familiar natural or man-made artefact or of an easily recognizable activity or story in order to use the typical associations to convey additional meaning about the content. Examples of such visual metaphors are tree depictions of science domains (as in Diderot and D'Alembert's famous Encyclopaedia), iceberg depictions of explicit and implicit knowledge, the visualization of a selection process by employing a funnel picture, or the visualization of an IT architecture as a temple structure with four pillars. Visual metaphors can be powerful catalysts for knowledge transfer and

learning as they support learners in connecting what they already know (the properties of the metaphor domain) with new material (the domain unto which the metaphor is being applied). Lakoff and Johnson [13,14] have demonstrated that metaphors are at the core of our cognitive abilities and can thus be used explicitly as cognitive tools in learning. This is especially true when the power of a metaphor is combined with the appeal and directness of visualization.[21] Nevertheless, visual metaphors also have a number of potential disadvantages.[23] Visual metaphors can divert attention from their content,[24] they can be unfitting for certain contexts (they can be seen as too playful), they can be manipulative and difficult to let go of or switch,[25] they can loose their benefit once they have been (over) used, and they may overemphasize commonalities among things that are essentially different.[26]

The graphic formats discussed above are obviously not the only visualization techniques that can be used to foster learning, yet they provide a number of advantages for knowledge construction that other, more complex visualization methods – such as flow charts, cognitive maps,[10,11] loop or system diagrams – may not be able to provide (i.e., reducing complexity, providing mnemonics, and facilitating rapid group communication).

Besides the comparison of the application parameters of concept maps, mind maps, conceptual diagrams and visual metaphors (in order to highlight potential complementarities), another method that is employed in this paper is the exploratory use of these methods in class room teaching. Different real-life examples of such maps will be shown to illustrate the benefits of combining various mapping techniques sequentially during a course. The examples can also illustrate the potential drawbacks when relying only on one mapping method.

Results and discussion: a comparative view of mapping methods

In this section we present the results of the comparison among the four approaches and the exploratory use of complementary mapping in university teaching. In the next section a synthetic table is presented and discussed which compares the application parameters of the four methods. An overview of the main advantages and disadvantages and a relative positioning (with regard to their use) is derived from this comparison. Based on these considerations a possible application sequence for teaching and learning purposes is suggested. In the succeeding section we present examples of the methods' use in classroom teaching.

A comparison between the four methods regarding their application parameters

While Novak's concept maps, Buzan's mind maps, theory-driven conceptual diagrams, and visual metaphors with embedded text have a number of attributes in common (such as the integration of text and image, the stepwise completion and the rule-based approach), they nevertheless differ with regard to their specific benefits and constraints. These differences are explored in Table 1. It summarizes the key features and main application parameters of all four methods. The first row of the table provides a thumbnail representation of each format to give an impression of the overall shape of the visualization method. The second row contains a short definition of the method. The three following rows position each method in terms of its typical application (main benefit or function, typical application context and application guidelines). The next two rows specify the visual vocabulary of the method in terms of the graphic elements, their reading logic, and their use (guidelines). The rows from 'macro structure adaptability' to 'understandability' qualify the methods in terms of their flexibility and complexity. These factors will be further discussed in a subsequent table that focuses on the advantages and disadvantages of each method. The final row indicates one possible software package for each format that can be used to draw or use an electronic version of the method.

A first glance at the key features of the four visualization methods reveals that their profiles are quite distinct: whereas concept maps and mind maps are great personal learning tools that result in individual solutions, conceptual diagrams and visual metaphors are tools for knowledge communication and joint knowledge construction. While mind maps and visual metaphors result in attractive, colourful and memorable results, conceptual diagrams and concept maps tend to be less memorable, because most of them look very much alike – a collection of boxes and arrows (with occasional icons).These generalizations do not apply to each and everyone's use of these formats; they nevertheless tend to follow the advantages and disadvantages of the four formats as they are discussed in the literature. Four main advantages and disadvantages of each method are summarized in Table 2.

From these profiles we can generate a first tentative positioning that can help us in using the four visualization techniques in complementary ways or even combine them into new visualization formats (as discussed in the conclusion). One possible way of positioning the four methods is by their ability to support the remembering of learned content and whether they are more geared towards personal or group use. Following this reasoning, mind maps would be best used for in- class, personal note taking, while concept maps should be used at home for review purposes (also because they take longer to develop). Conceptual diagrams can be used to develop concepts in class, while visual metaphors are a good way of summarizing them at the end of the class jointly with a greater level of detail.

One important common feature that all four visualization formats share (besides their common purpose of facilitating understanding), is that their *electronic use* allows for the linking or embedding of related additional material, such as other maps or diagrams, internet hyperlinks, documents or pictures.[18–20] This opens the opportunity

Table 2 Advantages and disadvantages of the four visualization formats

Format	*Concept map*	*Mind maps*	*Conceptual diagram*	*Visual metaphor*
Main advantages	1. Rapid information provision[15]	1. Easy to learn and apply[6]	1. Provides a concise overview[24]	1. Serves as a mnemonic aid (method loci)
	2. Systematic, proven approach to provide overview[15]	2. Encourages creativity and self-expression[5]	2. Structures a topic into systematic building blocks	2. Draws attention and in spires curiosity
	3. Emphasizes relationships and connections among concepts[17]	3. Provides a concise hierarchic overview[6]	3. Assures that main aspects are considered	3. Activates prior knowledge about metaphor domain[13,25–27]
	4. Ability to assess quality of concept map through evaluation rules[2]	4. Easy to extend and add further content[6]	4. Can be applied to a variety of situations in the same manner	4. Facilitates understanding by triggering functional associations[13]
Main disadvantages	1. Not easy to apply by novices; requires extensive training[17]	1. Idiosyncratic, hard to read for others	1. Can be difficult to understand without knowledge of category meanings	1. Cannot easily be extended or modified
	2. Concept maps tend to be idiosyncratic[17]	2. Represents mostly hierarchic relationships[6]	2. May not be applicable to the topic at hand	2. May be misunderstood, may trigger wrong associations
	3. Time consuming evaluation through tutors[17]	3. Can be inconsistent	3. Does not provide mnemonic help	3. Can be difficult to draw (rapidly)
	4. The overall pattern does not necessarily assist memorability	4. Can become overly complex (loss of big picture)	4. Does not foster creativity or self-expression	4. Can be manipulative or misunderstood[23]

to use such maps as navigational aids to electronic learning content or simply annotate entries with additional personal comments. The electronic use of these methods also makes it possible to use the methods as *ad-hoc* collective maps in class rooms or meeting contexts via a laptop and beamer. The conceptual diagram and the two visual metaphors discussed in the next section have been used in this way.

Application examples and experiences

As mentioned in the previous section, a complementary way to use the four visualization methods uses conceptual diagrams for in-class concept development, handwritten mind-mapping for in-class note taking, concept mapping for personal student reviewing at home, and visual metaphors for joint in-class summaries. This didactic logic is consistent with the relative advantages and disadvantages discussed in Table 2. Table 3 shows this didactic approach which uses the four methods in a complementary way and describes their application.

This logic has been applied in two bachelor classes (on knowledge management) and in two Ph.D. courses (on research methods):

First, a special type of *conceptual diagram* has been used to structure complex content during class presentations (see Figure 1) and lectures. At the beginning of the session, the diagram contained only the concept label, all other boxes were interactively filled in with occasional contributions from the students who had heard about the concept previously. Figure 1 depicts the completed diagram after approximately 20 min of discussion.

The picture depicted in Figure 1 is a specific type of conceptual diagram (that we call concept skeleton) that helps to explain the nature of an academic or abstract concept. Its benefit can be described as follows: Whereas Novak's concept maps mainly serve the purpose of student learning by having them list and connect various concepts through explicit labels, the main function of a concept skeleton is one of summarization and elicitation, and these tasks only regarding one single concept at a time: concept skeletons of this type thus help to transform sketchy ideas into systematic thoughts. Consequently, we define a concept skeleton as a one-page abstract diagrammatic representation of an abstract concept, its label, definition, elements, examples and implications, as well as its kind. The depiction also includes pointers to related concepts. A concept according to Novak [2] is a mental image of a thing or object. Our understanding of a concept is a bit more focused: A concept in this context refers to an elaborate abstract idea that has implications for action. The concept skeleton's elements can be characterized as follows:

- *Concept name or label*: A concise set of terms that gives the concept a label by which it can be referred to.

Table 3 A complementary use of the four methods based on their unique features

Didactic steps	*Applied visualization format*	*Didactic application mode*
1	Conceptual diagram	A new concept is introduced step by step (or box by box) in the class room by filling in an empty conceptual diagram that is completed iteratively and jointly.
2	Mind map	During the subsequent explanations and further elaborations, the students take notes by drawing personal mind maps.
3	Concept map	To test their understanding and recall, the students are asked to develop a concept map (at home) of the main contents and submit this map at the beginning of the next lesson. They can use the introductory conceptual diagram and their own mind map together a list of the key elements and then structure them using the rules of concept mapping.
4	Visual metaphor	In order to summarize the discussion on a topic in a memorable and insightful way, a rich visual metaphor is used that positions all discussed items within an appealing and self-explanatory metaphoric structure. This empty visual metaphor is given as a hand-out to students who can then add the jointly discussed items into their personal copy of the metaphor image.

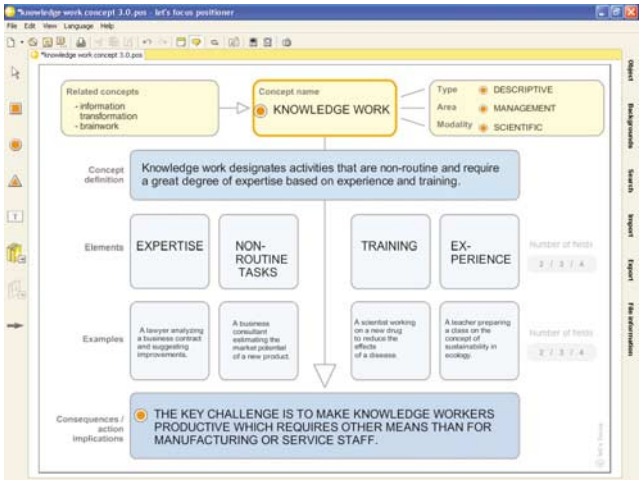


Figure 1 A concept skeleton used to jointly develop the notion of knowledge work in a bachelor class on knowledge management (drawn with lets-focus.com).

- *Concept type*, *area and modality*: These three sections indicate the nature of the concept that is described. In terms of type we distinguish whether the concept is a scientific concept (such as a research construct) or a practical one (such as an action principle) or both. The area describes the topic domain to which the concept can be related to. If the concept type is scientific this domain can be any scientific discipline, such as biology, physics, or geography. If the concept type is practical, then domain may refer to an operational area, such as project management, cooking, or architecture. The concept modality finally describes the nature of the concept's claim: is it describing a goal one should strive for, then the label given to the concept is normative, if it outlines the way something is actually done, it is descriptive, if it explains the way something works it is explanatory, and if it outlines a way to resolve a problem it is a prescriptive concept.
- *Related concepts*: This box lists similar, but nevertheless different concept labels that are closely related to the outlined concept.
- *Concept definition*: This box includes a few sentences that define the key idea behind the concept. Typically the definition also includes the key elements of the concept that are then also isolated in the element boxes below the definition box.
- *Elements*: This section lists the different subconstructs or subconcepts of the main concept.
- The *examples* or manifestation boxes provide real-life instances of the concept.
- *Implications*: This section summarizes the practical consequences of the concept or in other words how it should be applied and used.

The main benefit of such a concise depiction of a concept is that one can gain a systematic overview quickly and not only describe the concept but also analyze it in terms of its epistemic nature (i.e. its domain, goal, as well as the strength of its claims).

After this initial discussion with the help of a concept skeleton, detail content has been presented in a regular lecturing style. For this phase, ***Mind maps*** have been used for individual note taking during the class by the students (the mind maps have not been collected). Several studies have already highlighted the beneficial use of mind mapping for the purpose of note taking [29–31] and Buzan developed the method with note taking in mind as an explicit application area.[5,6]

In a third didactic step, ***Concept maps*** have been used as take-home assignments, where 30 students needed to individually summarize a module of the class (on knowledge work) with the help of concept mapping (see a sample concept map submitted by a student in Figure 2).

In a fourth step, ***visual metaphors*** have been used to structure in-class discussions with students systematically and document a lesson in a memorable way (see Figure 3).

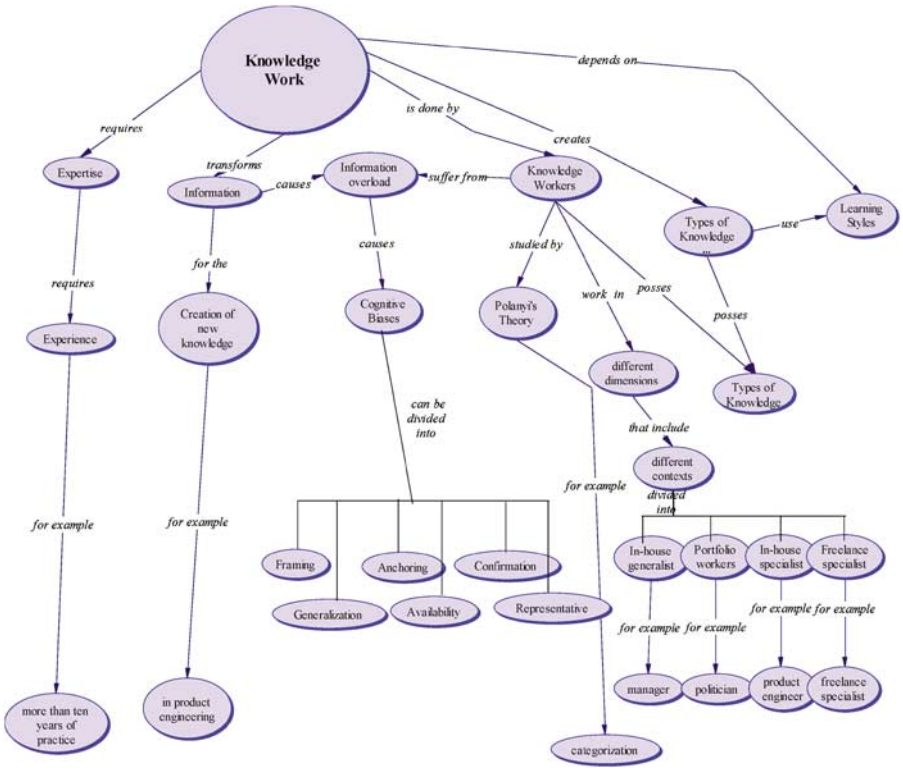


Figure 2 A concept map drawn by a student as an assignment and review tool for a class module (from a bachelor class on knowledge management, drawn with inspiration.com).

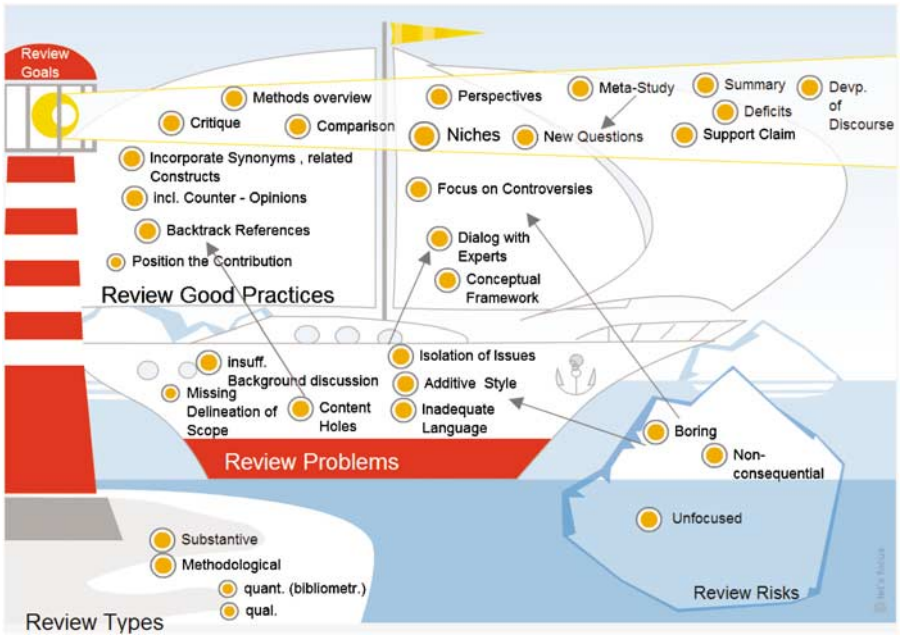


Figure 3 Whiteboard screenshot from an in-class jostle session on conducting literature reviews (conducted in a Ph.D. level seminar class, drawn with lets-focus.com).

At the beginning of each summary lesson the (beamed) visual metaphors only contained the labels of their different zones (such as review goals, review problems, review risks, etc.). Students were asked to propose goals or problems which the tutor entered in the respective area of the metaphor on the interactive whiteboard. The

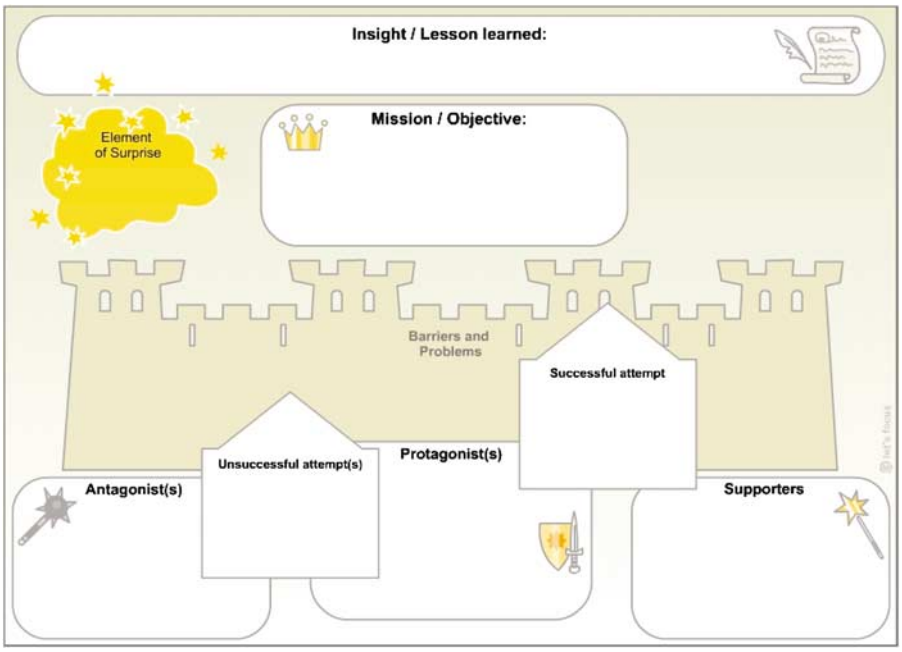


Figure 4 A mixed visual metaphor/conceptual diagram template to structure learning content in a narrative structure during a class room discussion.

visual metaphor shows the status of the discussion after a 40-min debate.

The preliminary results from these tests have been positive in the sense that students responded very favourably to this mix of visual methods. After an initial distraction due to the interactive whiteboard technology, the students remained focused and attentive, more than they would usually be in this type of discussion. The visual methods have kept them engaged and gave them ownership of the class content. In follow-up lessons, the discussed concepts seemed to be remembered better than usual. The fact that the students also asked for electronic copies of the jointly devised visualizations is another sign of their interest. Future follow-up studies should test these stipulated benefits and they should show whether this assumed higher level of attention, engagement and recall also translates into better learning results (and this even after the 'newness' of the complementary visual approach has worn off). In the current study, the course evaluation form and the final exam were used to assess the satisfaction and learning effects of the students, yielding positive results compared to prior courses. In addition, an independent Ph.D. student conducted half hour- to 1-h interviews with 14 students of the class asking them about the experience with the concept mapping assignment. The results of these interviews showed that the students require a lot of time, systematic assistance and feedback in order to devise high-quality concept maps. They revealed that some students had problems understanding the concept maps of others. They also highlighted the fact that the students' concept maps did not incorporate many of the provided multimedia material because I did not discuss that material in detail in class and I did not encourage them extensively to use that material. Two-thirds of the students chose to draw the concept map with mapping software inspiration.com while one-third produced concept map posters or paper versions. As a major benefit, the students mentioned that they were able to check their understanding and learning, to see new connections, and to repeat the key contents. In future studies, a questionnaire on what the students have specifically liked or disliked about all of the visualization sessions and exercises will be issued.

Conclusion: towards a complementary use of mapping methods

The systematic comparison of the four methods in terms of their application parameters and their exploratory use in teaching has shown that the combined, sequenced use of the four methods can provide a number of benefits that go beyond the possibilities of each individual method alone. In future research these exploratory findings should be examined using an experimental design with follow-up surveys among participating students in order to measure more accurately how the effects of the four methods differ. Such experimental studies could also reveal differences in student learning styles and a more adequate matching with respective visualization methods. In this way, one can analyze whether the additional cognitive load (and additional time investment) resulting from teaching more than one visualization technique has paid off in terms of a sustainable learning effect.

A different future research route is to develop *mixed-mode visualizations* that combine the strong points of the four methods, as for examples the straight forward rules of concept maps, the clarity of conceptual diagrams, the simplicity of mind maps, and the memorable richness of visual metaphors. A first effort in this direction has been made in Figure 4. It shows a conceptual, rule-based diagram that employs metaphoric elements to make its content more memorable. Yet such 'hybrid formats' are probably limited in their application scope: they make sense only for specific topics, as in this case a story plot visualization for procedural knowledge (to teach project management concepts). It is doubtful whether such formats could ever compete with the simplicity and application scope of concept maps or mind maps. Nevertheless, *inventing* such hybrid forms could also be a new way to foster the visual literacy of students: Besides applying ready-made visualization techniques to learning tasks, students could venture to create their own methods to represent and study learned content visually. They could, for example, develop re-usable graphic templates to be used by their peers in subsequent classes to structure key content of the class systematically. Related to this topic is another future research question regarding the differences between the software-based use of visual methods, and their 'analogue' application using pen and paper: Future studies should examine under which conditions and for which relative benefits software-based approaches (as the ones depicted in Figures 1–4) should be used, and in which contexts simple pen-and-paper methods may be superior. One obvious advantage of the software-based approach is that it lends itself easily to e-learning contexts where the visual methods can be viewed or edited remotely by all learners via application sharing.

Acknowledgements

Financing for this research has been provided by the Fondo Tasso -- Foundation for Research and Development. I thank Terry Inglese for conducting and transcribing the student follow-up interviews.

References

1 Novak JD. Learning theory applied to the biology classroom. *The American Biology Teacher* 1980; **42**: 280–285.
2 Novak JD, Gowin DB. *Learning How to Learn*. Cambridge University Press: Cambridge, 1984.
3 Novak JD. *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. Lawrence Erlbaum Associates: Mahwah, NJ, 1998.
4 Burkhard R. *Knowledge Visualization–The Use of Complementary Visual Representations for the Transfer of Knowledge. A Model, a Framework, and Four New Approaches*. Swiss Federal Institute of Technology (ETH): Zurich, 2005.
5 Buzan T. *Using Both Sides of the Brain*. Dutton: New York, 1974.
6 Buzan T. *The Mind Map Book*. 2nd edn., BBC Books: London, 1995.
7 Toulmin S. *The Uses of Argument*. Cambridge University Press: Cambridge, 1958.
8 Porter M. *Competitive Strategy*. The Free Press: New York, 1998.
9 Kaplan RS, Norton DP. *Strategy Maps: Converting Intangible Assets into Tangible Outcomes*. Harvard Business School Press: Boston, 2004.
10 Eden C. Analyzing cognitive maps to help structure issues or problems. *European Journal of Operational Research* 2004; **159**: 673–686.
11 Eden C. Cognitive mapping. *European Journal of Operational Research* 1988; **36**: 1–13.
12 Burkhard R, Meier M. Tube map visualization: evaluation of a novel knowledge visualization application for the transfer of knowledge in long-term projects. *Journal of Universal Computer Science* 2005; **11**(4): 473–494.
13 Lakoff G, Johnson MJ. *Metaphors We Live By*. University of Chicago Press: Chicago, 1980.
14 Lakoff G, Johnson MJ. *Philosophy in the Flesh*. Basic Books: New York, 1999.
15 Plotnick E. Concept mapping: A graphical system for understanding the relationship between concepts. ERIC document, June 1997, EDO-IR-97-05. [WWW document] http://www.alltech-tsi.org/toolkit/docs/ed407938.htm (accessed March 21, 2005).
16 Kinchin IM. If concept mapping is so helpful to learning biology, why aren't we all doing it? *International Journal of Science Education* 2001; **12**: 1257–1269.
17 Zeilik M. (n.d.). Classroom assessment techniques: concept mapping. [WWW document] http://www.flaguide.org/cat/minutepapers/ conmap1.php (accessed March 25, 2005).
18 Tergan S-O. Digital concept maps for managing knowledge and information. In: Tergan S-O and Keller T (Eds). *Knowledge and Information Visualization. Lecture Notes in Computer Science LNCS 3426*. Springer: Berlin, Heidelberg, New York, 2005; 185–204.
19 Cañas AJ, Carff R, Hill G, Carvalho M, Arguedas M, Eskridge TC, Lott J, Carvajal R. Concept maps: integrating knowledge and information visualization. In: Tergan S-O and Keller T (Eds). *Knowledge and Information Visualization. Lecture Notes in Computer Science LNCS 3426*. Springer: Berlin, Heidelberg, New York, 2005; 205–219.
20 Âhlberg M. Varieties of concept mapping. Concept maps: theory, methodology, technology. Proceedings of the First International Conference on Concept Mapping (Pamplona, Spain), Universidad Pública de Navarra, Pamplona, Spain, 2004.
21 Coyne R. *Designing Information Technology in the Postmodern Age, From Method to Metaphor*. MIT Press: Cambridge, 1995.
22 Ishikawa K. *Guide to Quality Control*. Asian Productivity Organization: Tokyo, Japan, 1983.
23 Blackwell AF, Green TRG. Does metaphor increase visual language usability? *Proceedings of the 1999 IEEE Symposium on Visual Languages VL'99* (Tokyo, Japan, 1999), IEEE Computer Society: Washington, DC, USA, 1999, 246–253.
24 Tufte E. *Envisioning Information*. Chesire: Graphics Press, 1990.
25 Coyne R. *Designing Information Technology in the Postmodern Age, From Method to Metaphor*. Cambridge: MIT Press, 1995.
26 Morgan G. *Images of Organization*. London: Sage, 1986.
27 Dent-Read CH, Klein G, Eggleston R. Metaphor in visual displays designed to guide action. *Metaphor and Symbolic Activity* 1994; **3**: 211–232.
28 Huff A. *Mapping Strategic Thought*. London: Wiley, 1990.
29 Mento AJ, Martinelli P, Jones RM. Mind mapping in executive education: applications and outcomes. *The Journal of Management Development* 1999; **18**(4): 390–416.
30 Sutherland P, Badger R, White G. How new students take notes at lectures. *Journal of Further and Higher Education* 2002; **4**: 377–388.
31 Farrand P, Hussain F, Hennessy E. The efficacy of the 'mind map' study technique. *Medical Education* 2002; **5**: 426–431.
32 Eppler M. *Conceptual Management Tools*. St. Gallen: mcm institute: University of St. Gallen, 1999.
33 Horn R. *Mapping Hypertext: Analysis, Linkage, and Display of Knowledge for the Next Generation of On-Line Text and Graphics*. Waltham: The Lexington Institute, 1989.