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

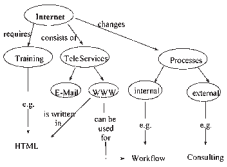
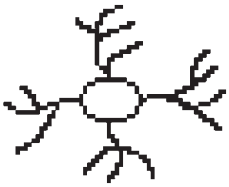
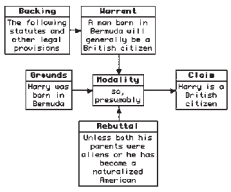
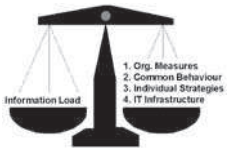
Format Parameters	*Concept map (J.D Novak)*	*Mind map (T. Buzan)*	*Conceptual diagram*	*Visual metaphor*
Sample thumbnail representation				
Definition	A concept map is a top-down diagram showing the relationships between concepts, including cross connections among concepts, and their manifestations (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