[Reference: Schwendimann, B. (2014). Concept mapping. In R. Gunstone (Ed.),
Encyclopedia of science education]

Concept Maps

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Synonyms or Key Words: Concept mapping, knowledge visualization, graphic organizer

DEFINITION: A concept map is a node-link diagram showing the semantic relationships among concepts. The technique for constructing concept maps is called "concept mapping". A concept map consists of nodes, arrows as linking lines, and linking phrases that describe the relationship between nodes. Two nodes connected with a labeled arrow are called a proposition. Concept maps are versatile graphic organizers that can represent many different forms of relationships between concepts. The relationship between concepts can be articulated in linking phrase, for example "leads to" (causal), "consists of" (part-whole), "follows" (temporal), "is inside of" (spatial), "increases" (quantified), or "is different than" (comparison). Nodes (usually nouns) and linking phrases (usually verbs) form a semantic network of propositions.

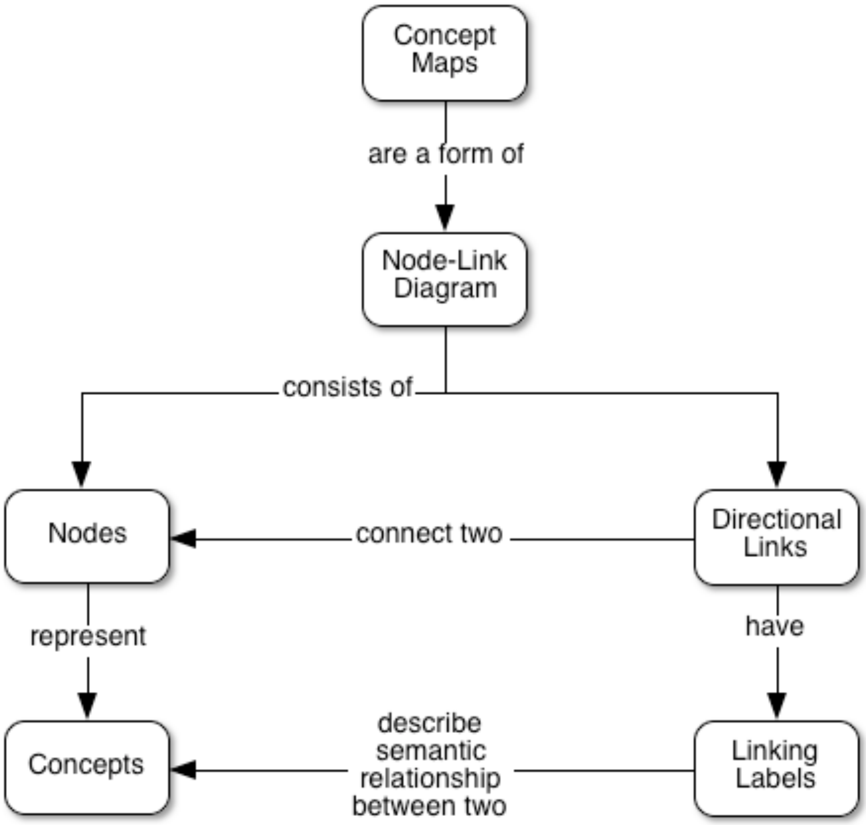

Figure 1: Concept map of a concept map

BACKGROUND: The theoretical framework of concept mapping is based on David Ausubel's assimilation theory of learning [See Ausubelian Theory; Meaningful Learning], which stresses the importance of individuals' existing cognitive structures [See Cognitive

Structure; Prior Knowledge] in being able to learn new concepts. Inspired by this framework, Joseph D. Novak and his research team at Cornell University in the 1970s developed concept mapping as a way of graphical representation of concepts, based on their research on understanding changes in children's knowledge of science (1984) [See Conceptual Change in Learning]. With its emphasis on actively engaging learners in eliciting and connecting existing and new concepts, concept mapping is considered to be consistent with constructivist epistemology [See Constructivism: Personal]. Concept map activities can support eliciting existing and missing concepts and connections through the process of visualizing them as node-link diagrams.

DIFFERENCE TO OTHER COMMON FORMS OF NODE-LINK DIAGRAMS: Various forms of node-link diagrams have been developed through history. Some of the earliest examples of node-links diagrams were developed by philosopher Porphyry of Tyros in the 3rd century AD to graphically visualize the concept categories of Aristotle. Commonly used examples of node-link diagrams are mindmaps, flowcharts, and concept maps. Mindmaps, popularised by Tony Buzan, are arranged in a radial hierarchy around a single central concept. Mindmap connections are non-specified associations that are represented by non-directional lines without linking phrases. Flow charts, first presented by engineer Frank Gilbreth in 1921, show the intermediate steps between input (e.g. problem) and output (e.g. solution) of a system. Flow chart connections are usually ontologically of the same kind, for example information, energy, time, or material. In comparison, linking phrases in concept maps can represent any forms of relationships (for example, temporal, procedural, functional, subset, superset, causal, etc.) [See Knowledge, Forms of] and topological arrangement (for example, hierarchical, hub, decentralized network, circular, etc.). Concept maps can be considered the most versatile form of node-link diagram.

CONSTRUCTION: Concept maps can be constructed by hand using paper and pencil, flashcards, post-its, or by using computer software (Exemplars are the freeware tool Cmap (http://cmap.ihmc.us/ or commercial tool Inspiration (http://www.inspiration.com). Research indicates that using concept mapping software can facilitate construction, revision, and addition of hyperlinks and multi-media (Canas 2003). Concept map can provide a how- or why-question as a "focus question" to describe the purpose of a concept map and guide concept map generation. Concept map setups can vary from open-ended to very constrained forms. Concept mapping tasks with few constraints can provide learners with a focus question while giving them free choice to select their own concepts and links. Medium constraint forms can provide learners with pre-made lists of concepts or linking phrases but give free choice of which concepts to connect. Highly constrained forms of concept maps can provide learners with a skeletal network structure and pre-made lists of concepts or linking phrases to be filled into blanks in the structure. Concept mapping requires initial training to familiarize learners with the concept mapping generation principles, and criteria for concept map evaluation.

CM AND LEARNING

Concept mapping can also be seen as a first step in ontology-building, and can also be used flexibly to represent formal argument. Concept maps have been studied as tools for lesson planning, as advanced organizers [See Advance Organizer], as learning tools, online navigation interfaces, knowledge management interfaces, or as assessment tools [See Assessment: An Overview]. Concept maps have been explored as learning tools in a wide range of different science disciplines (including chemistry, biology, earth science, ecology, astronomy, and medicine), from young children to adults, individual or collaborative construction, and asynchronous or synchronous construction. Meta-analyses indicate that concept maps as learning tools produce generally medium-sized positive effects on student achievement and large positive effects on student attitudes (Horton (1993); Nesbit and Adesope (2006), Canas (2003).

CM AND ASSESSMENT

Concept maps, especially more constrained forms, have been found reliable and valid forms of assessment for conceptual change of understanding science concepts. Research comparing concept maps to multiple choice tests indicates that concept maps assess different (for example propositional and hierarchical) forms of knowledge. Concept maps can reveal students' knowledge organization by showing connections, clusters of ideas, hierarchical levels, and cross-links between ideas from different levels. Cross-links are of special interest as they can indicate creative leaps on the part of the knowledge producer.

CM EVALUATION

Concept maps can be evaluated using quantitative or qualitative methods. Concept maps contain several elements that can be quantitatively evaluated: Links, concepts, hierarchy levels, and propositions. The number of links and concepts can easily be counted but provides limited insight into a student's understanding. Propositions are the most promising elements of a concept map to be evaluated in order to track changes in students' understanding. Proposition analysis can include all links or only a selection, value all propositions equally or attribute different weights. Research suggests that scoring only selected propositions can be more sensitive to measuring conceptual change because it focuses only on key concepts of the concept map. Concept map analysis often compares student-generated maps to an expert-generated map. This efficient analysis approach can provide instant feedback, but limits capturing the wide range of alternative expressions of understanding.

Qualitative analysis of concept maps can include network analysis methods focusing on the connectedness of selected concepts or topographical analysis methods to describe the overall geometric structure of the concept map.

ADVANTAGES of concept mapping

Different explanations have been proposed to explain the observed benefits of using concept maps. Concept maps activities can support eliciting existing concepts and connections [See Alternative Conceptions and P-Prims] and serve as a memory aid by off-loading them as external node-link diagrams. Concept maps can support learning science by identifying central concepts from different contexts. The explicitness and compactness of concept maps can help keeping a big picture overview.

In a concept map, each concept is represented by only one node, and all connections to related concepts are presented in one location. The 'gestalt effect' of concept maps allows viewing many concepts at once, increasing the probability of identifying gaps and making new connections. Visual chunking of related concepts or arranging concepts in hierarchies can reveal epistemological structures. Compared to written linear summaries, clustering related concepts into meaningful patterns can foster quick information retrieval. Additionally, concept maps use a simple syntax for propositions (node-link-node) and limited amounts of text to represent concepts. Fast information retrieval from concept maps can be beneficial for communication in collaborative settings [See Information Processing and Science Learning]. Viewing or generating concept maps may integrate concepts in both verbal and visuo-spatial memory. According to Paivio's dual coding theory, verbal and visuo-spatio concepts reside in separate but potentially interlinked memories. Integrating verbal and visuo-spatial concepts can provide alternative ways to retrieve concepts. Additionally, verbal and visuo-spatial concepts can be effectively simultaneously processed. Generating concept maps requires learners to represent concepts in a new form that can pose desirable difficulties - a condition that introduces difficulties for the learner that slow down the rate of learning and can enhance long-term learning retention. The process of translating concepts from texts and images to a node-link format may foster deeper reflection about concepts and their connections and prevent rote memorization.

LIMITATIONS
Similar to geographical maps, concept maps do not aim to include all but only a selection of concepts. Concept maps usually constrain connections between two concepts to a single relationship, which requires distinguishing and selecting between multiple possible relationships. Concept map construction requires an initial training phase to learn how to generate, interpret and revise concept maps. Generating, revising, and evaluating concept maps can be time consuming. More constrained forms of concept mapping can be faster and more reliably evaluated, but they only offer limited freedom to express one's understanding. The same concept or linking phrase can take on different meanings. Concept mapping activities can be beneficial to improve conceptual understanding, but may have limited effects on basic recall.

Implications for science education:
As a learning tool, concept maps can support eliciting core ideas and connections, and can make possible clusters or hierarchies visible. Graphic organizers such as concept maps can scaffold integration of students' isolated biology ideas to an organized interconnected network of ideas. Research indicates that the implementation of concepts maps can shift the epistemological authority from the teacher to the student, reduce emphasis on right and wrong answers, and create visual entry points for learners of varying abilities. Findings suggest that concept mapping as learning tools may be particularly beneficial for lower performing students by providing scaffolds and by modeling the active inquiring approach often found in higher performing students. When introducing concept mapping, the teacher should make the possible benefits for the learner explicit, for example to reflect, to communicate what would otherwise be incommunicable, or to keep trace of what otherwise would disappear.
Concept maps can not only be seen as cognitive tools that can elicit ideas and as meta-cognitive tools that can support the generation of self-explanations, but also as social artifacts through which students communicate. When concept maps are generated collaboratively, they become shared social artifacts that elicit existing and missing connections and spur discussion among students and teachers. The constraint to only one link between two concepts requires collaborators to negotiate which creates an authentic need to support arguments with scientific evidence.

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o Cross-References (references to other entries of this Encyclopedia)
[See Ausubelian Theory]
[See Meaningful Learning]
[See Cognitive Structure]
[See Prior Knowledge]
[See Conceptual Change in Learning]
[See Constructivism: Personal]

[See Alternative Conceptions and P-Prims]
[See Advance Organizer]
[See Assessment: An Overview]

o References (optional bibliographic references; should not exceed 5 and may be zero)

-Norton, P. B., McConney, A. A., Gallo, M., Woods, A. L., Senn, G. J., & Hamelin, D. (1993). An investigation of the effectiveness of concept mapping as an instructional tool. Science Education, 77(1), 95-111.

-Nesbit, J. C., & Adesope, O. O. (2006). Learning with concept and knowledge maps: A meta-analysis. Review of Educational Research, 76(3), 413-448

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

-A large catalog of papers on concept mapping: http://cmap.ihmc.us/Publications/