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A metacognitive tool: Theoretical and operational analysis of skills exercised in structured concept maps ☆

Marie-Pierre Chevron[a,b,*]

[a]Centre d'Enseignement et de Recherche Francophone pour l'Enseignement au secondaire, Université de Fribourg, Rue P.-A. de Faucigny 2, 1700 Fribourg, Switzerland
[b]Faculté des Sciences, Genève, Switzerland

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Abstract
Developing meaningful learning is not only difficult to achieve but also time consuming, because it requires a large number of different skills to develop and master. Many studies have shown that organizing knowledge in concept maps helps teachers and students to develop such a meaningful learning (Nesbit, J.C., Adescope, O.O., 2006. Learning with concept and knowledge maps: a meta-analysis. Rev. Educ. Res. 76:3, 413–446). Based on the work of Tyler (Tyler, R.W., 1950. Basic principles of Curriculum and Instruction. University of Chicago Press, Chicago, IL) and Anderson (Anderson, L.W., Krathwohl, D.R., Airasian, P.W., Cruikshank, K.A., Mayer, R.E., Pintrich, P.R., Raths, J., Wittrock, M.C., 2001. A Taxonomy for Learning, Teaching, and Assessing: A revision of Bloom's Taxonomy of Educational Objectives. Longman, New York), this study proposes to characterize and to organize precisely, rigorously, and operationally in a two-dimensional matrix, the skills exercised during the elaboration of concept maps, here referred to as context-dependent and hierarchically structured concept maps (sCM). These skills correspond to those actually needed in transfer of knowledge, and the matrix could be used as an instructional tool to assist learners and teachers in this transfer. In addition it allows them to pay attention to the cognitive processes and types of knowledge involved during sCM elaboration. Making explicit the taxonomic levels of cognitive efforts implemented while organizing knowledge in a concept map could constitute a useful metacognitive tool to focus the teachers and learners' attention and efforts towards achieving higher-order thinking skills and meaningful learning.

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*Corresponding author at: Centre d'Enseignement et de Recherche Francophone pour l'Enseignement au secondaire, Université de Fribourg, Rue P.-A. de Faucigny 2, 1700 Fribourg, Switzerland. Tel.: +41 26 300 76 11.
E-mail address: marie-pierre.chevron@unifr.ch

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Introduction

With the development of the World Wide Web, knowledge has become easily accessible to most people in all fields. Accompanying this accessibility, new constraints emerged for both teachers and learners: finding appropriate information on one hand and constructing meaningful knowledge within this wheat of information on the other hand. Indeed, once the information found, it still remains to verify their truthfulness, and to be able to link them together in order to construct, in precise, logic and explicit ways, a solid and reliable framework of knowledge. This requires understanding, analyzing, and evaluating what has been learned, and corresponds to a high degree of scientific expertise and advanced thinking skills. Teachers sometimes emphasize on memorizing information or specific terms (Mayer, 2002). Acquisition of knowledge is important, but not sufficient, and another essential goal in education is to promote the ability to use what has been learned (transfer) (Mayer, 2002; Mestre, 2002). Transfer of knowledge indicates meaningful learning (Mayer, 2001, 2002; Haskell, 2001). It requires learners not only to remember what they have learned, but also to solve new problems, answer new questions or facilitate learning of new matter in a different context. Such a meaningful learning is difficult to achieve because it requires multiple cognitive steps: retention, active and purposeful retrieval of specific terms or relevant concepts from long term memory and elaboration, differentiation, and integration of those concepts in organized cognitive structure (Atkinson and Shiffrin, 1968; Terry, 2006; Mintzes et al., 2005b; Karpicke, 2012). Based on Ausubel's learning theory (Ausubel, 1968), the key idea in meaningful learning is that the learner has to integrate gradually, through the mechanism of subsumption, new pieces of knowledge within existing pathways in his own cognitive structure (Mintzes et al., 2005a). In this perspective, concept map (CM)—tools representing knowledge in maps in which new material can be added—can help students to structure ideas and progressively construct mental representations of abstracts and complex concepts (Novack, 2008). Indeed, numerous studies (Nesbit and Adescope, 2006, and references therein) have shown that organizing knowledge in CM helps teachers and students to develop meaningful learning.

A CM is a graphical tool used to organize and represent knowledge (Novak and Cañas, 2006). In CM, concepts are enclosed within circles or boxes, and linked to each other by directed connecting lines. Words on the lines, or connectors, specify the relationship between the related concepts. An important characteristic of CM is that concepts are represented in a hierarchical way with the most inclusive and general concepts at the top of the map and the more specific and less general once located below. In addition, the presence of "cross-links" on CM highlights relationships between distant concepts in different segments or domains of the CM. These cross-links often represent new and thus creative links from the CM designer, highlighting a complex and integrated knowledge. Specific examples or objects that help clarifying the meaning of a given concept can be included in the CM. These are usually not written in boxes since they do not represent concepts. According to their founder, they are sometimes called "Novakian map" (Davies, 2011). Constructing such Novakian maps is difficult to achieve and the hierarchical polarity described above is not always observed. A qualitative approach analyzing student's concept maps highlighted three major patterns referred to as "spoke", "chain" and "net" structures (Kinchin et al., 2000). For a given scientific content represented, these maps differ in terms of complexity. An increased integration of pieces of knowledge is observed from spoke to net structures. A spoke structure contains only one hierarchical level and very simple associations, whereas a chain structure represents different levels of hierarchy, but often incorrect. In a net structure, elements are connected to each other and reflect complexes interactions at different conceptual levels and indicate meaningful learning (Kinchin et al., 2000; Kinchin, 2008). Similar representations have been observed in our practice over 5 years with learners in science classrooms in secondary school in Switzerland (aged from 13 to 20 years), as well as with student science teachers at the postgraduate or undergraduate level in University (pre-service science teacher training), both in Fribourg and Geneva (unpublished results; Racenet and Chevron, 2013). In a Novakian map, the hierarchical structure for a particular domain of knowledge depends on the context in which knowledge is considered, and a suitable way to clearly specify the domain to be explored is to construct a CM with reference to a focus question the CM seeks to answer (Novak and Cañas, 2006; Davies, 2011). Indeed, depending on a particular context, pieces of knowledge presented in a CM will be differentially organized. For example, a specific term like "DNA" can be related to different terms, whether describing cell function, DNA replication or heredity. Another important difficulty is to make choices, thus establishing priorities on the scientific notions, facts or concept being present on the map (Novak, 2008; Novak, 2010; Novack and Cañas, 2006). We also observed that CM designers strain to delimitate the domain to be explored. Indeed, when a focus question is presented to learners (students or student teachers), they tend towards deviating from the focus question and constructing maps related to a complete domain of knowledge, and rarely answer the asked question. Finally, a lack of rigor is observed to precisely define the relationships among elements inside CM (Kharatmal and Nagarjuna, 2010).

In this study, in order to explain and overcome the observed difficulties in constructing hierarchically organized CM, here referred to as "Context-dependent structured CM" (sCM), sCM related skills have been categorized in an explicit and operational way. Making explicit the taxonomic levels of cognitive efforts implemented while organizing knowledge in maps appears as an interesting metacognitive tool to focus learner attention and efforts towards achieving higher-order thinking skills. The sCM matrix, described in detail in the next section, is proposed to help, guide, and invite both teachers and learners for transfer in knowledge and thus meaningful learning.

Structured concept map (sCM)

I have used the Tyler matrix (Tyler, 1950) and the revised Bloom taxonomy (Anderson et al., 2001; Krathwohl, 2002), the latter proposing to organize in a two-dimensional table four major types of knowledge and six cognitive process