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Title: Mapping for meaning. Using concept maps to integrate clinical and basic sciences in medical education
Issue Date: 2014-09-25
CHAPTER 3

Consistent variations between concept maps constructed by medical experts and residents

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Submitted
Abstract

Background Preconstructed concept maps are valuable for integration of clinical and basic sciences in medical education. They are mainly constructed by experts. However, concept maps constructed by residents are hypothesized to be less complex and to contain more basic science concepts organizing the map. Experts are expected to articulate more links between clinical and basic science concepts.

Aim To investigate consistent variations, particularly regarding integration of clinical and basic sciences, between expert and resident concept maps.

Method Seven multidisciplinary expert teams and seven teams of residents with an equivalent disciplinary composition constructed a concept map. The concept maps were analysed along a framework of features that described integration of clinical and basic sciences.

Results The hypotheses were partly verified: the residents used basic science concepts as a device to organize the clinical and basic science concepts. However, their concept maps also exhibited a significantly higher degree of organization and links between clinical and basic science concepts, thereby articulating links between basic science concepts and history, physical examination, lab research and diagnoses. Integration in experts' maps concerned mainly diagnoses.

Conclusions The explicitness of resident concept maps resembles the ‘intermediate effect’ reported by medical expertise studies. By using more organizational devices, resident concept maps seem to surpass expert maps in complexity.
3.1 Introduction

During their training, medical students need to learn to connect their clinical and basic science knowledge in order to become proficient doctors (Boshuizen, 2004; Boshuizen & Schmidt, 2000). Medical curricula aim to scaffold this learning (Dahle et al., 2002). For helping students to develop a knowledge base that integrates clinical and basic sciences, schematizations such as concept maps seem to be promising (Daley & Torre, 2010; Kinchin et al., 2008). Concept maps articulate concepts and their interrelations in a hierarchical way (Novak, 2002) and thus visualize the relations between clinical and basic science concepts that should be understood in order to understand a medical subject (Kinchin et al., 2008; Weiss & Levison, 2000). Students can construct concept maps by themselves (Daley & Torre, 2010; Edmondson & Smith, 1998) but concept maps that are constructed by teachers (hereafter referred to as ‘preconstructed concept maps’) also scaffold student learning (Cutrer et al., 2011; Rendas et al., 2006; Weiss & Levison, 2000).

3.1.1 Level of expertise

Using preconstructed concept maps in medical education raises the question of how complex they should preferably be. The complexity of a concept map, that is the number of concepts, links and layers in hierarchies (Novak, 2002), increases with the expertise of its constructor (Edmondson & Smith, 1998; Rendas et al., 2006). Some authors take the position that for undergraduate medical programs preconstructed schematizations such as concept maps should preferably be constructed by experienced clinicians or basic scientists in order to foster the development of an expert-like knowledge organization (Coderre, Mandin, Harasym, & Fick, 2003; Mandin et al., 1997). However, concept maps that are constructed by experts might not be optimal for educational purposes. They might be too complex and consequently impose a task on students that is too far above their current knowledge level. It is then unlikely that learning will take place (Kirschner, Sweller, & Clark, 2006).

We do not know how and to what extent integration of clinical and basic sciences is articulated in concept maps that are constructed by experts and experienced medical teachers. Nor do we know whether concept maps that are constructed by constructors on different expertise levels, such as medical experts and residents, differ consistently with respect to articulation of integration of clinical and basic sciences. Experts and residents possess both theoretical and practical medical knowledge but differ in the way that clinical and basic science knowledge are embedded in their knowledge base (Boshuizen, 2004; Boshuizen & Schmidt, 1992). This difference might be visualized in their concept maps because they visualize the
constructors’ understanding (Kassab & Hussain, 2010; Rendas et al., 2006; West et al., 2000).

3.1.2 Integration of clinical and basic sciences in concept maps

Literature on the knowledge base of clinicians has fuelled expectations about the articulation of integration of clinical and basic sciences in concept maps (Boshuizen & Schmidt, 1992, 2000; Eva, Norman, Neville, Wood, & Brooks, 2002; Feltovich et al., 1993). There appear to be salient differences between experts and residents with respect to the organization of their knowledge base and the way that clinical and basic science knowledge is related. Such insights enable us to hypothesize differences in concept maps of experts and residents.

The first difference might be in the articulation of basic science concepts. As medical expertise develops, basic science knowledge gradually becomes encapsulated by clinical concepts as a consequence of clinical exposure. This is evidenced by studies showing that medical experts mention fewer basic science concepts when they diagnose patient cases (Boshuizen & Schmidt, 1992; Van de Wiel, Boshuizen, & Schmidt, 2000) than residents that have not yet ‘wrapped up’ their basic science knowledge in clinical knowledge to the same extent (Boshuizen & Schmidt, 1992; H. G. Schmidt & Boshuizen, 1992). It is during the residency that basic science knowledge gradually becomes intertwined with situated, clinical knowledge (Boshuizen, 2004; Boshuizen & Schmidt, 1992). Hence, residents might more easily articulate basic science concepts in concept maps than experts.

Another difference between expert concept maps and resident concept maps might be the use of clinical – often diagnostic – concepts to organize the concept map. When experienced clinicians recall patient cases, they tend to use clinical summaries or higher order clinical concepts whereas 6th year students, for example, articulate many more detailed concepts of a basic scientific nature (Boshuizen & Schmidt, 2000; Van de Wiel et al., 2000). Experts use these higher order clinical concepts to organize the information they give about a patient case. Hence, we hypothesize that the organization of expert concept maps relies more on clinical concepts that encapsulate basic science concepts, whereas residents are expected to use basic science concepts for the organization of the concepts.

The third characteristic that might distinguish expert and resident concept maps emanates from the cohesion that pervades expert behaviour. By means of a knowledge network with a high density of interrelations between concepts (Eva, Norman, et al., 2002; Feltovich et al., 1993; Genberg, 1992; Koedinger & Anderson, 1990), experts bring together symptoms and complaints into a diagnosis or underlying basic science mechanism (Eva, Norman, et al., 2002; Feltovich et al., 1993). They are
inclined to connect data from a holistic viewpoint (Eva, Norman, et al., 2002). We hypothesize that this holistic viewpoint results in more links between clinical and basic science concepts in expert concept maps compared to resident concept maps.

From the perspective of educational use, it seems worthwhile to explore differences between concept maps that are constructed by experts and residents. Insights into these differences could enable us to make decisions about the expertise level of the constructors of preconstructed concept maps and the role of residents in curriculum development in order to fit the needs of medical students and to scaffold them to build up an integrated knowledge base. Resident concept maps might be less complex than those constructed by experts, are expected to unveil more basic science concepts that help to understand clinical concepts and might differ from expert maps in how the integration of clinical and basic science concepts is organized. Expert concept maps, on the other hand, are expected to express integration by means of more links between concepts. So far, there have been no studies focusing on the articulation of integration of clinical and basic science concepts in concept maps constructed by groups of constructors with different expertise levels. Moreover, studies that map out differences in complexity of concept maps aim to elicit knowledge structures of individuals (McGaghie, McErimmon, Mitchell, Thompson, & Ravitch, 2000; Rendas et al., 2006; West et al., 2000) whereas concept maps for educational purposes are preferably constructed by groups of constructors in order to achieve consensus about the content of the program (Coffey et al., 2002).

We questioned what consistent variations are found in concept maps constructed by groups of experts, and by groups of constructors at resident level. Variations might be expected regarding the complexity of organization, as previous research on concept mapping has shown (Markham, Mintzes, & Jones, 1994; McGaghie et al., 2000; West et al., 2000), but also regarding the number of basic science concepts and links between clinical and basic science concepts and the extent to which clinical and basic science concepts are used for organizing the concept map.

3.2 Methods

3.2.1 Context and participants

We conducted a study at Leiden University Medical Centre that aims to offer an integrated bachelor curriculum. Seven expert groups and seven resident groups constructed a concept map, each group consisting of three participants, at least one clinician and one basic scientist. The multidisciplinary character of the groups was expected to contribute to the articulation of their knowledge due to the information gap between the participants. The experts had at least 5 years' post-graduation
experience. The participants in the resident groups were doing their residency or were following their specialization program as basic scientists.

### 3.2.2 Materials and procedure

Each group was asked to construct collaboratively a concept map about a clinical problem. The clinical problems emanated from internal medicine but were also relevant for other clinical disciplines: coughing, diarrhoea (2x), proteinuria, blood in faeces, chronic abdominal pain and articular pain. Each clinical problem was schematized in a concept map by an expert group and by a resident group that had an equivalent disciplinary composition. Involved disciplines were internal diseases (different subspecialities), surgery, gynaecology, general practice, radiology, anatomy, immunology, microbiology and pathology. Diarrhoea was schematized twice but the disciplinary composition of the groups differed.

The concept maps were created during two sessions that lasted two hours. In the first session, the participants were guided through concept mapping instructions that were designed to support visualization of integration: the constructors were instructed to contribute concepts that were particularly relevant from the perspective of their own discipline and to explore links between clinical and basic science concepts (see Box 2.1 for the instructions). They then had to explain two complex patient cases using the concept map in order to check whether the map was comprehensive. Concept maps were created using post-it notes and big paper sheets and were digitized using Inspiration®, a software tool for creating concept maps. The second session was spent on checking the digitized version and on elaborating and fine-tuning the concept map. Appendix 2 shows one of the concept maps on blood in faeces constructed by a resident group: a GP who contributed general data, history, and obstipation treatment, a surgeon whose contribution focused on degenerative aspects, history and physical examination, while a pathologist contributed degenerative and inflammation aspects. The Institutional Board of Leiden University Medical Centre, where the concept maps were constructed, provided ethical approval for the study.

### 3.2.3 Data analysis

A framework of features was developed to describe the concept maps. The features enabled us to quantify differences between expert and resident concept maps, in particular on the issue of integration. We distinguished concepts (clinical concepts and basic science concepts); organization (umbrella concepts and clinical-problem-specific umbrella concepts); and integration (clusters, hierarchies and links).
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*Concepts:* in Appendix 2, the clinical concepts are those concepts under general data, history-taking and physical examination, lab research, diagnosis and interventions. The basic science concepts are distinguished by grey nodes. Resident concept maps were expected to cover relatively more basic science concepts than expert concept maps. Therefore, the proportion of both were computed.

*Organization* of the concept maps was measured by umbrella concepts. All rectangular concepts in Appendix 2 are interpreted as umbrella concepts. We distinguished general umbrella concepts that are applicable to every clinical problem (in Appendix 2, for example, history-taking, physical examination, lab research and differential diagnosis) and umbrella concepts that are specific to the clinical problem of the concept map such as tractus digestivus high, infectious, colour: bright red in Appendix 2. Umbrella concepts that are clinical-problem-specific have been shown to correlate with level of expertise (Coffey et al., 2002; Rendas et al., 2006; West et al., 2000).

*Integration* is described by means of clusters, hierarchies and links. Integrated clusters are groups of at least one clinical and one basic science concept placed (either hierarchically or non-hierarchically) close to each other. See Appendix 2: tractus digestivus high and the five concepts – loss of weight, loss of blood, epigastric discomfort, gastric acid and nausea/vomiting – are interpreted as a cluster because it contains both basic science concepts and clinical concepts.

In a hierarchy, there is always an umbrella concept that is explained by one or more other concepts. Two types of integrated hierarchies were distinguished and counted to measure differences in expert and resident concept maps: clinical concepts encapsulating basic science concepts (Appendix 2, loss of blood encapsulates tractus digestivus high and tractus digestivus low) and basic science concepts that subsume clinical concepts (Appendix 2: infectious subsuming ulcus ventriculi and ulcus duodeni).

Links between clinical and basic science concepts were counted, mapping out links between basic science concepts and 1. history and physical examination, 2. lab research, 3. diagnosis, and 4. interventions in order to gauge the role of integration in the different phases of clinical reasoning. An example in Appendix 2 is the link between the concepts “digital rectal examination” and “mechanic”. Links could articulate either hierarchical or non-hierarchical relations. Experts are expected to generate more links between clinical and basic science concepts than residents as a reflection of a more holistic view (Feltovich et al., 1993).
Two researchers analysed the concept maps and decided what should be considered as a concept or a cluster. Some concepts could be interpreted as either one or two concepts (e.g. the basic science concepts ‘inflammation: histology’ in Appendix 2). Consensus was achieved about the interpretations, so that discrepancies that were irrelevant to our aim would not blur the analysis. Subsequently, the concept maps were analysed along the feature framework described above by two researchers. Part of the data was analysed by another researcher in order to check the interrater reliability of the analysis. Cohen’s kappa ranged from .87 to 1.00. The mean Cohen’s kappa was .95. Differences between concepts of experts and residents were analyzed by paired t-tests.

### 3.3 Results

Table 3.1 shows the differences between expert concept maps and resident concept maps as measured by concepts, organization and integration. Overall, the number of clinical and basic science concepts used by the two expertise levels did not significantly differ. However, the resident concept maps tended to be more elaborate. The proportion of basic science concepts and clinical concepts differed slightly between the two expertise levels. Standard deviations were relatively high.

| Table 3.1: Means and standard deviations for the features that describe the concept maps |
|----------------------------------|---------------------------------|------------------------------|------------------------------|------------------|
|                                  | Resident concept maps N=7 mean | SD                           | Expert concept maps N=7 mean | SD               |
| **Concepts**                    |                                |                              |                              |                  |
| Clinical concepts               | 85.6 (75%)                     | 18.3                         | 70.7 (79%)                   | 19.7             |
| Basic science concepts          | 28.3 (25%)                     | 21.3                         | 19.1 (21%)                   | 7.6              |
| **Organization**                |                                |                              |                              |                  |
| Total umbrella concepts:        | 24.9                           | 6.7                          | 14.6                         | 3.6              |
| general umbrella concepts       | 7.0                            | 3.8                          | 5.3                          | 3.8              |
| clinical-problem-specific umbrella concepts | 17.9 | 6.7 | 9.6 | 3.3 |
| **Integration**                 |                                |                              |                              |                  |
| Clusters of clinical and basic science concepts | 11.9 | 3.3 | 2.3 | 3.7 |
| Hierarchies:                    |                                |                              |                              |                  |
| clinical concepts encapsulating basic science concepts | 0.7 | 1.5 | 2.9 | 3.9 |
| basic science concepts subsuming clinical concepts | 9.4 | 3.9 | 2.6 | 4.4 |
| **Links between clinical & basic science concepts:** | 24.0 | 6.0 | 6.9 | 4.8 |
| history, physical examination + basic science | 6.3 | 3.5 | 0.9 | 1.2 |
| lab + basic science             | 4.3                            | 2.9                          | 0.3                          | 0.5              |
| diagnosis + basic science       | 11.1                           | 5.7                          | 5.1                          | 4.2              |
| interventions + basic science   | 2.3                            | 2.5                          | 0.6                          | 0.8              |

* p < 0.05  ** p < 0.01
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The organization of the expert concept maps and resident concept maps differed significantly. The concept maps at resident level encompassed significantly more umbrella concepts, that is concepts that subsume other concepts (24.9 versus 14.9) due to significantly more clinical-problem-specific umbrella concepts (17.9) than the expert concept maps (9.6).

To visualize integration, the resident groups gave basic science concepts a prominent role, leading to significant differences with the expert concept maps as Table 3.1 shows. They clustered clinical and basic science concepts more frequently than experts (11.9 versus 2.3) and structured the hierarchies significantly more along basic science concepts than experts did (9.4 basic science umbrella concepts that subsumed clinical concepts in contrast to experts with 2.6). Although not statistically significant due to a fairly high spread, experts employed clinical concepts as an organizational device more frequently (2.9 versus 0.7).

Contrary to our expectations, links between clinical and basic science concepts were used significantly more frequently by the residents (24.0 versus 6.9). Additionally, we investigated which type of clinical concepts were preferably linked with basic science concepts: history and physical examination, lab research, diagnosis or interventions, to get an impression of when the use of basic science concepts seems important in the clinical reasoning process. All these 4 combinations were articulated more by residents with significant differences between resident and expert concept maps when basic science concepts were linked to history and physical examination (6.3 versus 0.9) and to lab (4.3 versus 0.3), again underlining the role of basic science in the concept maps at resident level early in the clinical reasoning process.

The quantitative differences in organization and integration between the resident and expert concept maps became apparent in their appearance. In some resident concept maps, a concept-map-like appearance, that is concepts structured in a hierarchical way, was combined with a matrix in which the headings of the columns were basic science categories. One of the resident groups described this as ‘the magical ruler’ that helps us to understand the clinical concepts. In the expert concept maps, mainly clusters were linked (instead of concepts), resulting in a relatively low number of links. This strengthens the image of the expert concept maps as resembling archipelagos, as one of the expert groups described the process of organizing the concept maps: 'let’s make islands, so that we can do some island hopping'. This metaphor adequately describes the organization of most expert concept maps: clusters of concepts based on the diagnostic process: history taking and physical examination, lab research, diagnosis and interventions.
3.4 Discussion

This study demonstrates that concept maps that are constructed by residents can be distinguished from expert concept maps on features that are relevant for curricula aiming to integrate clinical and basic sciences. Hence, it provides strong support for a consideration and investigation of the role that preconstructed resident concept maps could play in medical education. The resident groups used more clinical-problem-specific umbrella concepts to organize their maps, which is at odds with previous studies on concept mapping that show that the higher the expertise level, the higher the degree of organization (Markham et al., 1994; McGaghie et al., 2000; Rendas et al., 2006). Moreover, the resident concept maps articulated decidedly more integration between clinical and basic sciences.

How did integration become apparent in the resident concept maps in contrast to expert concept maps? We hypothesized three variations between the concepts maps at the two expertise levels. First, the hypothesis that residents would articulate more basic science concepts than experts could not be completely supported. Overall, their concept maps contained more basic science concepts but the difference was not significant, due to the fair variation with respect to the number of concepts they covered. Second, based on findings in think-aloud protocols in studies on knowledge organization (Boshuizen & Schmidt, 1992; Van de Wiel et al., 2000), the resident groups were expected to use basic science concepts for the organization of the concepts whereas medical experts were expected to rely on clinical concepts that encapsulate basic science concepts. The resident groups did indeed organize their maps through one organizational device – basic science categories – and hardly used clinical concepts and they did this significantly more than experts. The data on the organization of expert concept maps were partly consistent with our expectations and showed only a slight preference for clinical concepts that encapsulated basic science concepts. Medical experts used both devices to organize and integrate the clinical and basic science concepts in their map. Such a flexible use of two devices to organize their concept maps might develop with the expertise level of the group of constructors, a process that is equivalent to the growing flexibility in using reasoning strategies and knowledge of individual clinicians (Eva, Brooks, et al., 2002). However, overall, the experts were reluctant to organize their concept maps along hierarchical devices. Third, the hypothesis that experts would articulate more links between clinical and basic science concepts than residents due to their holistic approach to solving problems (Feltovich et al., 1993; Koedinger & Anderson, 1990) turned out not to be the case. Residents proved to be more ‘expressive’ than experts in the use of links to articulate integration of clinical and basic science concepts. Both groups preferred to connect basic science concepts with diagnoses but residents also...
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articulated links between basic science concepts and concepts earlier in the clinical reasoning process: history, physical examination and lab research.

The composition of the expert groups might have contributed to the finding that hierarchies and links remained unarticulated in their concept maps. Although the multidisciplinary composition of the groups was assumed to create an information gap that would affect the need to share and therefore articulate knowledge, the experts might have been aware of the fact that they all were indeed experts, evoking more concise explanations. The social dimension might have influenced the process of concept mapping: experts among experts might tend to explicate less assuming that their interlocutors could rely on the same knowledge base. This might also explain why experts left hierarchical relations unarticulated, linked clusters instead of concepts, and followed the diagnostic reasoning process by using relatively many general umbrella concepts like history and physical examination. In further research, the social dimension of constructing concept maps could be manipulated by groups consisting of both residents and experts, possibly resulting in articulation of relations by experts. Furthermore, the experts, often involved in medical teaching, aimed to reduce the complexity of the concept map. This fine-tuning of the concept map for educational purposes – scaffold for preclinical and clinical students – might have encouraged them to leave relations implicit which in other studies might have been articulated (Kassab & Hussain, 2010; McGaghie, Boerger, McCrimmon, & Ravitz, 1996; Rendas et al., 2006). Residents seemed to bother less about the complexity of the concept maps.

The expressiveness of the resident groups regarding integration reminds us of the intermediate effect described within the context of encapsulation theory: intermediates tend to mention not only more basic science mechanisms but also more clinical data than experts (Van de Wiel et al., 2000). Although the resident groups in our study are surely more knowledgeable than the intermediate levels that are referred to in these studies, they showed the same tendency when they constructed concept maps in groups. In order to explore whether there is indeed an intermediate effect in concept maps that are constructed in groups, this study should be duplicated with students who are expected to construct less elaborate concept maps. Note that the intermediate effect in previous studies addressed the knowledge structures of individuals (Van de Wiel et al., 2000), while an intermediate effect in our study concerns what groups of constructors jointly decided to be relevant links and organization in preconstructed concept maps.
3.4.1 Educational implications

Evidently, we need to be cautious with our conclusions because of the limited number of concept maps that we were able to include in this study. However, the consistent explicitness of concept maps constructed by the resident groups might make them more suitable for scaffolding undergraduate students than expert preconstructed concept maps. In particular, the interrelatedness between clinical and basic science concepts articulated in clusters, hierarchies and links might support students as they attempt to integrate clinical and basic science knowledge. Furthermore, the articulated relations between history, physical examination and lab research on the one hand and basic science concepts on the other hand might be helpful for medical students, because these relations often remain underexposed in medical curricula (Prince & Boshuizen, 2004). Whether students would experience resident preconstructed concept maps as a better format for scaffolding their knowledge acquisition requires further investigation. The increase in complexity due to the articulation of integration may be counterproductive for student learning.

Medical knowledge is suitable for application in clinical practice when it is organized around clinical concepts (Boshuizen, 2004; Prince & Boshuizen, 2004). Educational programs aim to scaffold medical students to achieve such fit-for-practice knowledge organization. Expert concept maps are in congruence with the knowledge organization that should be acquired in the long run, exhibiting two organizational devices: clinical concepts encapsulating basic science concepts and basic science concepts subsuming clinical concepts. It is thus counterintuitive to provide students with a scaffold that mainly visualizes one organizational device. However, organizing clinical concepts along basic science concepts might be a necessary developmental phase in the building of a sound integrated medical knowledge base. Intermediate preconstructed concept maps could therefore complement a clinically oriented medical program by bridging the gap between expert knowledge organization and student knowledge organization.
References


