Review Article

Concept mapping in basic sciences education: a teaching-learning, feedback and assessment tool

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Abstract

Concept mapping is a recent innovation in teaching-learning strategies that has yielded promising results in medical education. It is based on the theoretical premise that meaningful learning occurs when the connections between various concepts are understood. In the first year of the medical undergraduate course, students struggle to assimilate new concepts and fall back on rote memorization. It is predictably difficult then for students to relate superficial learning of the basic sciences to clinical application in their later years of study. Concept maps assist in the facilitation of deep learning and serve as effective learning resources. The active, personal process of identifying different concepts and illustrating the links between them helps students organize their knowledge structures and achieve higher-order learning. The use of serial concept maps and pre-prepared concept maps enhances the impact of teaching-learning experiences even in a traditional curriculum. Besides getting a graphic picture of the explicit learning that has occurred from concept maps, instructors would also be able to identify specific misconceptions and provide valuable, personalized feedback to improve understanding. The role of concept maps in assessment needs to be explored further though. Efforts to evolve valid, reliable ways of scoring them have shown that concept maps probably measure characteristics of learning that are not tested by the traditional assessment formats. This review intends to shed light on the fundamental aspects of concept mapping and its potential uses in basic sciences education.

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Introduction

Medical education is currently witnessing a paradigm shift from the traditional, disease-oriented approach to the integrated, patient care-centred approach.[1] The principle of societal obligation has questioned the practice of producing knowledge experts rather than care experts. Providing care involves exercising competencies in the attitudinal domain with respect to the patient's feelings and perceptions. There is another aspect to it, namely, the attitude towards learning, which will in turn influence the quality of the cognitive processes that occur in an individual. A competent practitioner must have the right attitude towards learning to be able to apply cognitive principles effectively in his practice.

Good healthcare demands a critical evaluation of the facts that are unique to every patient and real practice is about the consistent, competent use of

integrating, reasoning and problem-solving skills. In the traditional approach to medical education, the mainstay has been an unrealistically aligned, linear exposure to disciplinary perspectives. The learning experiences offered seldom encourage integration and critical evaluation, which is so dissociated from the requirements of real practice.[2,3]

In order to deliver high-quality services, healthcare practitioners are required to develop an integrated knowledge structure by an active, personal process.[3,4] A knowledge structure is a highly-integrated framework of related concepts built by a person's cognitive processes.[5] Every individual 'constructs' his own knowledge structure by interacting with the environment and draws conclusions based on it to solve problems.[2] Knowledge structure theory implies that individuals are influenced by their prior knowledge or pre-existing knowledge structures when participating in problem-solving activities.[6] Learning is accomplished when pre-existing knowledge structures are built upon and expanded to accommodate new concepts. Therefore, teaching-learning experiences should provide the means for integrating new learning with prior learning. It is important to set the appropriate context for this cognitive exercise to occur, rather than simply ensure the technical transfer of new information. Hence, there is a need for medical educators to explore better ways to facilitate the development of integrated knowledge structures.[3] Such efforts would translate to deep learning and consequently, greater competence in the healthcare professions.

Since there are a number of complex situations that challenge a practitioner's competence, the medical student must train to develop into a professional who fully learns how to learn and become a self-directed, life-long learner.[2,7] The term 'meaningful learning' encompasses this point of view. According to the meaningful learning or assimilation theory proposed by David Ausubel in 1968, knowledge cannot be based exclusively on memorization but should rather be i) understood, ii) significantly relevant and iii) well-integrated.[2] "Useful" knowledge is that which is well integrated with previous knowledge – has a context - and is stored in such a way that it can be accessed from different starting points.[8] To help students achieve meaningful learning, medical educators worldwide are looking into strategic tools that have stemmed from the prevalent theories of learning.

Concept mapping, developed by Novak and Gowin in the 1980s, evolved from the assimilation or meaningful learning theory.[9,10] It is also based on constructivist theories, such as Jean Piaget's Genetic Epistemology theory which postulated that previous knowledge is used as a net to understand and learn new information.[2] From his studies with children, Piaget arrived at the suggestion that moral and cognitive abilities are not completely inherent but a result of complex interactions between the individual and his environment.[11] Therefore, taking into account that each individual is a being who builds his own history, adult education ought to respect the autonomy and the dignity of each individual and develop a teaching-learning strategy based on this foundational principle.[2]

A concept map or a mind map is a useful teaching-learning innovation that recognizes the individuality of the learner by exploring the learner's existing knowledge structure and clarifying the context in which the new learning takes place.[12] It helps students visualize links between new concepts and their previous learning.[2] Every individual carries his knowledge in a personal cognitive net as he goes through several learning experiences.[2] By exposing the learner to previous knowledge assembled in his cognitive net, concept mapping helps him see how it links with the new information presented.[2] This interaction between the individual and the concept aids in the construction of knowledge and results in meaningful learning.[2,13]

The method of concept mapping and its uses have been reviewed, both conceptually and empirically, in medical education literature for its potential role in transforming the processes of learning, instruction, feedback and assessment. This review presents the fundamental components of a concept map, the theoretical principles that concept mapping is based on and the basic steps involved in the construction of

a concept map. Further, curricular experiences with its implementation and the implications of its use in basic sciences education have been elaborated on.

What is a concept map?

Simply stated, a concept map is a diagrammatic representation of a set of concept meanings in a framework that shows the links between them.[14] It is a graphic tool for organizing and representing knowledge as concepts depicted in a hierarchical order of importance.[14] Students write down the concepts they consider important in a topic, proceeding from the more general to the specific, and link them with a few words called qualifiers. Usually, concept maps tend to be read from the top downward and use arrows to link related concepts with suitable phrases such as "cause...", "leads to..." or "comprises of...".[2,15] However, they should not be confused with flowcharts as they do not have a rigid temporal or directional sequence, nor are they organised as a power hierarchy.[2]

Concept maps serve to present an integrated view of the relationships between various concepts that otherwise are frequently fragmented in different cognitive compartments.[2] The issues with a fragmented delivery of concepts would become apparent if one were to consider the analogy of how information is stored in a computer system. When searching for an important document on the desktop, everyone would have hit the panic button some time or other on seeing it crowded with all kinds of files - fragmented pieces of information – that were accumulated over time expecting that they would be required urgently some time soon. If not for the availability of labeled local drives, specific tabs and named folders, along with the provision of direction paths, one would not be able to access the required document for a specific purpose in good time. Likewise, concept maps help label the location of a concept clearly. They build a cognitive web in which the new concepts are incorporated and provide the means for integration of knowledge.[2] The establishment of such a meaningful net of knowledge is a fundamental step in the construction of a cognitive structure in any given subject.[2]

What are the principles underlying the framework of a concept map?

Any teaching-learning strategy must be based on sound educational principles to transform the learning experience to a meaningful exercise. A basic understanding of the principles that govern the theoretical framework of a concept map will help in the preparation of an effective, well-connected scheme. Ausubel and his co-authors have outlined three processes that they believe are involved in thinking and learning with concepts: subsumption, progressive differentiation and integrative reconciliation.[16]

Subsumption refers to the logical incorporation of lower-order concepts under higher-order concepts.[17] A concept is grouped under, above or with related concepts according to the relative extent of knowledge it represents. The process of subsumption leads to the creation of a hierarchy of knowledge structures.[18] Progressive differentiation involves breaking up a concept into finer and finer components, thereby detailing it, as is the case with the process of analysis.[14] Integrative reconciliation is the process of establishing links between the concepts on either side of the map.[14] It serves to identify the similarities or differences between concepts situated at opposite ends of the map. Thus, the visible cross-links between apparently distant and isolated concepts help the student comprehend new associations and acquire a deeper understanding of the subject; this dynamic, higher-order reasoning about conceptual relationships is similar to the process of synthesis.[8,14]

How to create a concept map?

The process of creating a concept map involves identifying concepts, selecting them by importance, and finding hierarchical relations between them.[9] It requires the active engagement of the learner at each step.[14] Learning with concept maps involves making an intentional effort to link, differentiate and relate concepts to each other in a hierarchical fashion.

The first step is to identify the more general, more inclusive concepts and place them at the top of the map.[14] Then, the more specific concepts – the answer to the 'focus' questions - that relate to the general concepts in some way are to be identified and ordered below them in a hierarchical manner. Here, the principles of subsumption and progressive differentiation are applied to decide on how the specific concepts must be ordered.[14]

Next, the various concepts are connected by lines accompanied by a few keywords, the qualifiers, which clearly spell out the nature of the relationships between the concepts. The meaning of the relationship, as conveyed by the concepts and such connecting keywords, is termed a proposition.[15] A concept map, in other words, presents an integrated framework of propositions. Once the obvious propositions have been depicted, the diagram must be reviewed to look for horizontal and cross-links - the step that illustrates integrative reconciliation.[2]

There is no one way to draw a concept map and the learner gets better at the exercise with practice.[2] As learning progresses, more concepts may be included, existing propositions may be revised or new propositions may be developed. Thus, concept maps are quite flexible and can be revised when there are improvements in the learner's understanding of the subject, when new knowledge is added or when there is a change in the conceptual basis of a subject.[2] Concept maps can be created with paper and pencil, or they can be created using one of many computer-based software programs, for example, CMAP Tools.[14]

The steps outlined above help the learner visualize the cognitive structure he has developed at the end of a teaching-learning experience and deepen the meaning that the new learning will acquire by providing it with a graphic context. Apart from its use by students to illustrate the learning they have accomplished, concept maps could double up as effective instructional resources too. In this case, a teacher would first fit in concepts that the student is familiar with and then guide him to establish its links with the new concepts he is required to learn, building on the principles of progressive differentiation and integrative reconciliation.[2]

The layout of a concept map can take one of various forms: A *web* layout has the main subject-matter placed in the middle of the map; a *hierarchical* form presents the information in a descending scale of importance. The *landscape* structure is adopted when information needs to be displayed in panoramic contexts and the *flowchart* is used when information is presented in a linear fashion. The *conceptual* layout finds middle ground by retaining the flowchart structure but with the possibility of inserting or excluding new concepts. *Multi-directional* concept maps are employed when depth is needed to represent relationships and two-dimensional representations cannot display the relationships adequately.[2]

Although the figure may seem overwhelming to a beginner, once the aspects of its construction and use are understood, it will become evident that a concept map actually informs the reader of the salient features in a clear, concise manner. The reader could proceed from the top in any direction he chooses, by asking a 'focus' question and finding the qualifier term – the set of words in small case - that would answer it. The qualifier would then through arrows lead the reader to the next concept printed in an adjacent box, which may prompt another question and a search for the appropriate qualifier and so on. This way, each reader gets a unique view of the subject, depending on the question he poses, which in turn depends on the priming he has undergone by his prior knowledge structures. It therefore follows that the construction of a concept map – its layout, the identified concepts and the choice of qualifiers - too would depend on the unique cognitive processes of the person drawing it up.

Experiences in the use of concept mapping in basic sciences education

There is a growing body of literature which indicates that the use of concept maps in medical education is increasing.[14] An extensive literature review that

investigated the usefulness of concept mapping in medical education found that concept maps function in four main ways:[14]

i) Concept maps promote the development of meaningful learning

Studies have indicated that through the use of concept maps, students were able to integrate basic and clinical science information and demonstrate critical thinking abilities within their disciplines. In this context, it is to be noted that it was the dissatisfaction with a traditional didactic curriculum that led to the problem-based learning (PBL) approach. The PBL strategy uses real-life scenarios to engage students by activating their prior knowledge, increasing understanding of basic science concepts, and organizing compartmental knowledge to construct a rich, elaborate, and well-integrated knowledge structure.[19] It has been shown to foster learning and transfer knowledge from the theoretical to the clinical context.[19] In studies where concept maps were integrated into the delivery of PBL approaches, the two tools appeared to complement each other.[9]

Additionally, concept mapping was found to foster the development of group and collaborative learning. In one study, findings indicated that students who were in triads of individuals with very different knowledge structures showed greater improvements in their learning than students who were in groups with more similar knowledge structures.[20] This has special significance in the light of the competencies required of an Indian medical graduate who must be trained to serve the roles of a team player and a communicator. Concept mapping, as a group activity, may have a potential role in fostering the requisite skills.[21]

ii) Concept maps function as a resource for student learning and curriculum development

Concept mapping is a creative activity that makes students reflect on their understanding of the concepts in a particular body of knowldege.[14] They gain a better understanding of the organization and integration of important concepts.[17] Research has also indicated that an integrated knowledge structure, rather than compartmentalized knowledge, is a prerequisite for successful problem-solving.[22] Integrating information involves the assimilation of individual concepts, identifying the links between them and recognizing underlying patterns. Physiology lends itself beautifully to integration as it is concerned with interactions between different organ systems and is governed by a few repetitive general patterns.[23] An example of a concept map illustrating a physiological concept that links with biochemical phenomena is provided in Figure 1. However, first-year students find the subject challenging as they perceive it as a mass of individual pieces of information.[24,25] This experience has been aggravated by the system-by-system approach that encourages conceptual compartmentalization by students.[23] Using concept maps in teaching physiology will get students to fit the bits of information into an organized scheme that brings out the big picture and will help them visualize the integrative nature of physiology.[24]

Interestingly, an exhaustive meta-analysis has revealed that concept mapping is more effective for promoting knowledge retention and transfer than reading text, attending lecture, or class discussion.[27] This difference was attributed to greater learner engagement with concept mapping than with reading or listening.[27] Any innovative teaching-learning strategy must lead to improvements in assessment performance to be considered effective in a given curriculum. A recent study that investigated the use of concept mapping as a learning tool in biochemistry reported that the new concept-mapping program resulted in higher academic performance compared to a traditional course and was perceived favorably by the students.[28] Another interesting finding from a study that will need additional research is that using concept maps in problem solving had the most impact on students who came into the study with the lowest cognitive competence.[29] Besides, researchers have found that learning style does not play a role in the ability to perform well on concept maps.[30]

In one study, serial concept maps were introduced in graduate education to demonstrate the evolution of a student's thinking over time.[14] A serial concept map is defined as a series of evolving maps created about a single concept over a specified time period.[31] As learning is a continuous process, serial concept maps have the potential to serve as a tool for intermittent monitoring of students' progress and clarifying faulty conceptual relationships.[14] Large classes may pose the problem of time constraints in the regular follow-up of individual assignments on concept maps though. This could be tided over by the use of pre-prepared concept maps which could be integrated into traditional instructional methods.[32] For example, to summarize a topic, the teacher could project a concept map showing only the hierarchical propositions and the linking arrows with the horizontal and cross-links omitted.[23]

As mentioned earlier, concept maps can support the development of PBL curricula. In another innovative way, concept maps can be of assistance in developing a curriculum by serving as a blueprint for the development of curricular goals and objectives. The integration of curricular themes between different disciplines can be charted out, clarifying the collaborative roles of each department.[33] As a lot of resources go into the delivery of an integrated curriculum, it is essential to develop an integrated route map and here, concept maps could give a lucid idea of when and what kind of individual departmental inputs should be factored in to meet a higher-order curricular goal.

iii) Concept maps could provide feedback about student learning

Concept maps reveal a student's construction of connections in a subject. They provide information about the mental representations of concept associations. Concept map assignments often expose student misunderstandings and misconceptions and therefore afford extra teachable moments.[24] Thus, concept maps allow instructors a clear view of the students' cognitive structure and are likely to facilitate timely provision of the appropriate inputs to further learning. When the meaning-making process is shared between the instructor and the student, deeper learning takes place.[14,24] If maps are assigned, graded, and returned before an exam, students have more opportunities for the information to fall into place.[24]

iv) Concept maps could assist in assessment of learning and performance

Although this function of concept maps is yet to be explored widely, a few studies have thrown light on how concept maps developed by students could be reliably scored, both quantitatively and qualitatively, to reward their critical thinking and understanding. While structural scoring is based on the map's organization of hierarchical structure, concept links and cross-links, relational scoring is based on the quality or importance of each component, with no regard to the overall structure of the map.[14] Generally, concept mapping assessment (CMA) scores improved after course instruction and the similarity of student maps with instructor maps increased significantly following instruction. An interesting finding in a study by West et al was that CMA scores did not correlate with final course or standardized test scores.[3] This observation led to the suggestion that concept mapping seemed to evaluate how students organize and use knowledge in a way that traditional tests did not.[14]

Challenges in concept mapping

Some students have a difficult time learning to develop concept maps, and this is likely due to previous emphasis on rote-mode learning.[34] The resistance to learning with concept maps is usually related to the time it takes to construct them and to the students' inability to understand their role in improving their performance in the traditional assessments.[3] After an initial orientation to concept mapping, students may have to be helped with the construction process until they elaborate well-structured concept maps.

Similarly, teachers may require some experience with the tool before they get comfortable in using it as a regular teaching-learning strategy in their courses. It

requires a shift from a content-oriented approach to a process-oriented form of instruction.[23] Moreover, initial exercises with concept mapping are likely to be too time-consuming.[23]Another issue to be considered is that since concept maps reflect a person's unique cognitive processes, experts may produce a wide variety of concept maps on the same subject.[35] Therefore, the challenge of assessing concept maps also needs to be looked at. Recent research has led to the evolution of assessment rubrics and multiple scoring systems for concept maps that have to be investigated further to ascertain the correlation of CMA scores with those of other standardized assessments.[14]

Conclusion

Concept mapping is an innovative educational strategy with a wide variety of applications in medical education. As a teaching-learning strategy, it promotes meaningful learning that is expected to foster the development of reflective physicians who would critically evaluate the clinical information presented to them and make the most appropriate decisions regarding patient care. This process requires drawing links between the learning of basic sciences and the clinical experiences, which could be facilitated by the use of serial and pre-prepared concept maps. The potential use of concept mapping as a valuable learning tool and feedback resource in the medical curriculum is supported by studies that have reported improved understanding and favourable student perceptions, although their influence on summative test scores requires further research. As the construction of a concept map is a personal process, instructors get to visualize the conceptual learning that each student has individually accomplished, and are enabled to provide objective and specific feedback to further comprehension. The use of concept maps as an assessment strategy poses challenges in terms of the validity and reliability of the scoring systems employed. A few studies have worked on developing assessment rubrics but further research is necessary to investigate how concept mapping would correlate with standardized assessments in medical education. As the long-term outcome of any curricular reform is to produce a competent professional, longitudinal studies are needed to ascertain the role of concept mapping in assisting medical students while they make the transition.

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Figure 1: An example of a concept map illustrating aspects of glucose homeostasis;[26] The central concept is glucose homeostasis which is a result of the interplay of other biochemical concepts, effected by insulin and glucagon.