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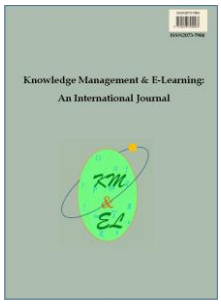

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A scoping review comparing different mapping approaches pointing to the need for standardizing concept maps in medical education: A preliminary analysis

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Abstract: This study aims to analyze how visual tools, labeled as maps, are built, and used in medical education. Based on the educational model of concept maps (CMs), proposed by Novak and Cañas (2008), and adapted to medicine by Daley and Torre (2010), we are currently analyzing the results of a scoping review following the PRISMA extension methodology, specifically for these purposes. Other visual tools, such as knowledge maps (KMs) and mind maps (MMs), used in medical education, were also included. The search was made through the databases EBSCO, PubMed/MEDLINE, PsycINFO, Scopus,

and Eric, using the following items: "concept map*", "knowledge map*", "mind map*" and "medical education". Only articles in English were considered and exclusively in medical education, from undergraduate to resident training. The analysis of selected articles included the following features: construction rules (if they followed Novakian instructions), teaching area, student level (undergraduate, postgraduate/residents), and use for assessment. Other features were the capacity to relate basic science knowledge to clinical concepts, the use of maps with other educational methods, such as problem-based learning (PBL), and providing feedback to students. From a quantitative perspective, the use of CMs is dominant in all phases of medical education. A failure to follow Novakian rules was found in around half of the articles labeled as CMs and KMs. As for MMs, which follow different rules for construction and use, they were considered relevant in helping students to summarize and retain information. Simultaneous use with other educational methods was only found with CMs.

Keywords: Concept map; Knowledge map; Meaningful learning; Medical education; Mind map; Novakian rules; Scoping review; Visual diagrams

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Pedro Carreiro-Martins (h-index: 24), is an Associate Professor of Pathophysiology at NOVA Medical School and a consultant of Allergy and Clinical Immunology. In the last few years has teached Pathophysiology to medical students using problem-based learning and concept maps.

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1. Introduction

Despite the widespread use of visual diagrams in education, it is difficult to understand why they are not more widely applied considering their undisputable role as a tool to facilitate teaching and promote learning. When consulting the literature, it appears as if

visual diagrams are used in a very heterogenous manner and, sometimes, as a simple sketch to visually illustrate a sequence of interrelated data or ideas. This approach curtails sharing experiences due to the lack of a common ground for debate and improvement.

An obvious exception has been concept maps (CMs) developed by Joseph Novak and his team at Cornell University (Novak & Cañas, 2006b), based on Ausubel's assimilation theory of cognition, which aim at enabling meaningful learning. These tools have been applied in different stages of education, from children to adults, and in multiple scientific areas. Even though Novak's group developed detailed instructions on how to build and use CMs (Novak & Cañas, 2006a), these recommendations were not always followed (Cañas et al., 2015) making it sometimes challenging to evaluate the role of CMs in meaningful learning. One of the main difficulties relates to the lack of standardization in the building and organization of CMs. This methodological heterogeneity limits the comparison between the results from different research projects and doesn't allow for overall conclusions related to the use of CMs in teaching and learning.

We have found three literature reviews dealing with mapping in medical education. Two from the same research group (Daley & Torre, 2010; Daley et al., 2016), concluded that CMs are useful tools to promote meaningful learning. The third review (Pudelko et al., 2012), extended the analysis to health professional education and included CMs and Mind Maps (MMs), which were considered as being used "often interchangeably", and raised concerns about the role of mapping in supporting "meaningful learning, memorization or factual recall". This statement confirmed the need for our study now that a decade has elapsed.

Based on our longstanding experience in medical education, as pioneers of problem-based learning (PBL) in Portugal, and long-time users of CMs (Fonseca et al., 2020a), we identified this lack of standardization of CMs as a relevant problem and decided to perform a scoping review of the literature. Because other visual diagrams are currently used in medical education, the search also included MMs (Abdel Hamid, 2017) and Knowledge Maps (KMs) (O'Donnell et al., 2002). The objective of this scoping review is to identify whether the use of these maps is relevant to teaching, learning, and assessment, at all levels of medical education.

2. Methods

As for this review, the definitions of the type of maps were as follows: CMs – top-down diagram formed by a set of concept meanings embedded in a framework of propositions; KM – top-down diagram formed by nodes and links connected to a previously defined set of linking words; MMs – radial diagram formed by a central word that is linked to other subheadings through named branches, forming hierarchies and accompanied with colors and illustrations. (Buzan, 2006; O'Donnell et al., 2002; Eppler, 2006). We define Novakian Concept Maps as maps following the Novakian rules: concepts written within a box, connected with one or more other concepts through linking words, forming a proposition. They must be written from top to bottom hierarchically, starting from the main concept, and cross-links and examples can be included (Novak & Cañas, 2006b; Kinchin, 2015).

A literature review was performed following the PRISMA extension methodology developed for scoping reviews (Tricco et al., 2018). We searched in four databases (PubMed, Web of Science, ERIC, and Scopus), for articles published from the date when the first one (CMs, MMs, or KMs), was identified and up to May 2022. The following

search terms were used: "concept map", "knowledge map", "mind map" and "medical education". Three different searches were made, one for each type of visual diagram.

The inclusion criteria were articles written in English, with research done only in the area of medical education. Studies of all designs (quantitative, qualitative, and mixed methods) were included. Articles about the use of concept maps or other diagrams in patient education/knowledge structures, to present results in medical research, involving other health students (like nursing, dentistry, nutrition, psychology, or physiotherapy students), were excluded from this review. We also excluded non-indexed journals, books/essays and commentaries, because most of the texts were not submitted to the standard peer-review process occurring in scientific journals.

A data-charting table was developed by two authors, defining the relevant variables to be extracted for this study. Two reviewers charted the data independently and manually, reading article by article, and added the results to a shared Google Sheets® form. During the data-charting process, we noticed that Knowledge Maps as expert maps are mostly mentioned as "expert concept maps".

The selected articles were analyzed regarding the following: 1. Rules used to build the maps; 2. Role of cross-links in the organization of the maps; 3. Isolated versus continuous applications; 4. Maps as formative tools (study group and self-learning) versus assessment instruments; 5. Specific teaching area (basic or clinical sciences). Concerning the advantages of using maps the following pedagogical features were considered: 1. Display the integration of relevant information relating basic science knowledge to clinical concepts; 2. Capacity to represent the effects of teamwork on building the maps as a foundation to be developed in clinical training and practice; 3. Simultaneous use of maps with other educational strategies such as PBL; 4. Feedback given to the students during the use of maps.

3. Results

Concerning CMs, 362 citations were identified from which 215 full articles were assessed for eligibility and 79 were included. As for KM, the values were 33, 24, and 2, respectively. Whereas for MMs the results were 44, 33, and 13, respectively, using the criteria mentioned above (Fig.1). The results are listed in Appendix I.

The first article analyzed describing the use of CMs in medical education was published in 1988, much earlier than MMs which only appeared in 2002. The total number of articles published per year was also very different, with a ratio of CMs/MMs always higher than 6/1, per year (Fig. 2).

All the map types were used more in undergraduate education than in postgraduate training and this feature was particularly relevant for CMCs (87%) and less for MMs (77%).

The Novakian rules were explicitly followed only in 42% of the CMs although an additional 19% mentioned those rules in the methods section. This feature was also difficult to check because 26% of the articles had no illustrations. The use of CMs for assessment only occurred in 30% of the articles. Finally, CMs were applied simultaneously with other pedagogical methods (PBL, case-based learning, and team-based learning) in 21% of the cases.

In the case of MMs, the use for assessment only occurred in 23% and no simultaneous use with other teaching methods was described.

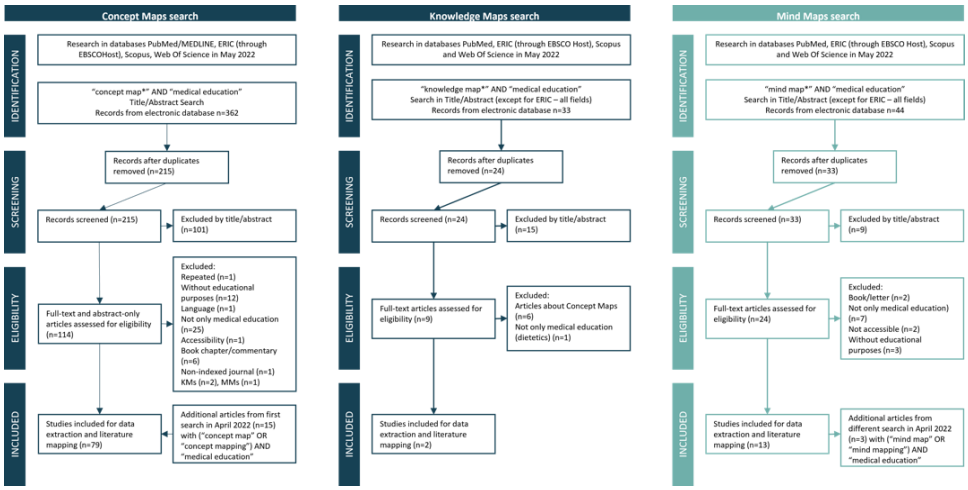

Fig. 1. PRISMA Flowchart for the scoping review

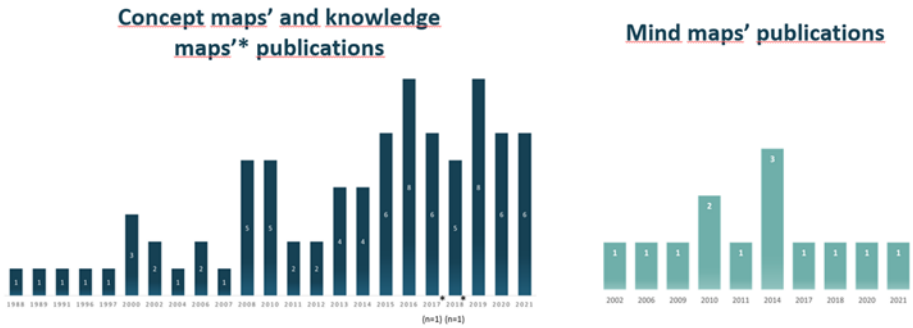

Fig. 2. Yearly numbers of the articles included in the scoping review

4. Discussion

To evaluate the proposed dual mapping learning environment, a series of studies and analyses were arranged. At the initial stage of the project, the evaluation was focused on learners' perception and reaction toward the system as reported in this paper. The assumption is that unless the proposed learning environment is properly designed and implemented to the extent that learners find it useful and acceptable, further exploration of the effect of the dual mapping learning environment may not produce reliable and meaningful results.

Considering the preliminary phase of our data analysis the results will be discussed addressing the following features of CMs/KMs versus MMs.

4.1. Teaching and learning medicine with concept and knowledge maps

4.1.1. Integrating knowledge from basic sciences to clinical concepts and promoting critical thinking and clinical reasoning

One of medical education's biggest challenges is to share expert medical knowledge during teaching and learning activities. The knowledge structure of an expert implies networks of understanding and chains of practice and the rapid transfer of information between them; for students to be able to achieve this level of metacognition when solving a problem, they need to shift their thinking from the linear (text) structure to the hierarchical (cognitive) structure and back again. This is a fundamental educational problem, for example in science teaching and learning. When experienced physicians, with highly competent skills, share their knowledge in the context of medical education based on their chains of practice (from repeated actions and networks), this type of knowledge is not easily transferable to students, because it lacks clarity when attempts are made to demonstrate the flux of knowledge. CM can be a way of displaying expert knowledge adequately, which would help students who are trying to acquire that level of clinical expertise and reasoning (Kinchin et al., 2008). In addition, when intentionally using core concepts as a bridge between basic sciences and clinical concepts in a concept map, students are drawn to find connections between basic and clinical science and their relations to medical practice. As was seen in a study by Slieman and Camarata (2019), this strategy of map construction promotes the reflection on the relationship between theoretical and practical concepts, and through the process of concept map peer review, a continued improvement of knowledge integration could be demonstrated. CMs can also be used within Case-based Learning (CBL) exercises or constructed to solve a clinical vignette (Spicer et al., 2020; Peñuela-Epalza & De la Hoz, 2019; LeClair & Binks, 2020; Torre et al., 2017; Wu et al., 2016; Muthukrishnan et al., 2019), helping students contextualize basic science concepts underpinning clinical medicine.

CMs were also reported to be used during Clinical Physiology Grand Rounds (CPGR), where CMs can be helpful to establish relationships between concepts of physiology (basic sciences) and clinical medicine (clinical practice) (Richards et al., 2013). When solving clinical cases, CMs can also be used to analyze the type of reasoning and cognitive processes students use (Smith et al., 2014; Wu et al., 2014), from inductive or deductive reasoning to pattern recognition/scheme-inducted reasoning, and this information can be useful to facilitate teaching and learning (Pottier et al., 2010). Other benefits include facilitating correlating prior knowledge from several disciplines (Azer et al., 2013), developing insights into new existing knowledge (becoming more conscious about their learning style) (González et al., 2008; Torre et al., 2007), and knowing how to transfer knowledge to future problems (Daley et al., 2016), namely in clinical practice (Torre et al., 2007). CMs are reported to encourage students to think independently (Small, 1988) and more inductively (Hayes et al., 2017). This exercise, therefore, appears to promote clinical reasoning, critical thinking, and problem-solving skills (Torre et al., 2013; Small, 1988), which are necessary to create meaningful experiences when students in clinical years encounter clinical settings.

4.1.2. Working in teams during learning is the first step for real life as a physician

CMs can be used individually or in groups. When working in groups, the process of constructing a map implies not only sharing knowledge, experience, and ways of thinking

and reasoning within a topic or a clinical case but also sharing a lack of knowledge between users and misconceptions that other users can identify during the discussion (Torre et al., 2017). This whole experience is called distributed cognition, and it involves social, interpersonal, and cultural components of cognition that expand our understanding of a learning experience beyond its traditional boundaries. The whole process of constructing a map in groups is a resource of distributed knowledge, having a role in the construction and reconstruction of the individual's knowledge, creating an active learning approach to the material to be learned (Bixler et al., 2015). An interesting example is the application of concept maps in Near-Peer teaching (NPT), where students from a more advanced level in their program can share their knowledge with less advanced students, creating a climate that fosters relationships between colleagues and a sense of help and cooperation, as described by the participants (LeClair & Binks, 2020). Besides the advantages of sharing knowledge, the whole experience of working in a team can be amplified into gaining awareness about working in a multidisciplinary team, as it happens every day in clinical practice. If students representing various professions or areas of knowledge would develop their map - based on their understanding of the case from their perspective – it could provide a moment of awareness of where and how professional roles intersect in actual clinical practice. This finalized map can also be a very useful study tool to specify the different roles of each member of an interdisciplinary team, providing a way to differentiate their roles (Daley et al., 2016). A study from the University of Leiden that involved heterogeneous groups, formed by experts and residents, facilitated multidisciplinary cooperation through problem-solving (Vink et al., 2015). The skill of interacting with professionals of other areas of expertise in the discussion of medical problems is part of everyday life as a physician, being therefore very relevant for medical students during their studies.

4.1.3. Complementing other medical educational strategies

CMs can also be used together with other teaching methodologies applied in medical education. CMs have been used within PBL (Addae et al., 2012; Si et al., 2019; Kassab & Hussain, 2010; Kassab et al., 2016; Alamro & Schofield, 2012; Torre et al., 2016; Drareni, 2018) - as they are constructed answering a core question, their applicability in solving a clinical problem showed to be complementary (using the clinical information of the case as a trigger). Rendas et al. (2006) showed that this "case-specific model" of concept mapping is appropriate because it manages to relate the relevant clinical information of the case with the pathophysiological mechanisms involved, thus fostering meaningful learning. Addae et al. (2012) adopted a method of PBL with CMs, reporting higher scores on a control questionnaire that explored the cognitive domain of learning, the metacognitive domain, and interpersonal relations. This method made students participate more and ask more questions, fostering deep learning. Si et al. (2019) explored the components of argumentation to solve clinical cases in a PBL course. In this study, first and second-year medical students mapped their arguments when solving clinical problems using CMs. When assessed in a written exam, the students improved during the PBL sessions regarding clinical reasoning and clinical problem-solving performance. CMs can also be taught to students in a PBL-based curriculum to enhance self-regulated learning (Thomas et al., 2016). In a study by Richards et al. (2013), students in clinical years that used CMs in this context stated that these tools helped them achieve better diagnoses and patient management plans; and students in preclinical years stated that CMs encouraged the use of inductive reasoning, through which they could remember and relate concepts better. In teaching evidence-based medicine, CMs appear to be more valuable than lecture-based methods. In a study by Saeidifard et al. (2014),

groups that used CMs scored more on the diagnostic and pathophysiology questions. They concluded that by using this tool, students could learn the most relevant medical evidence faster and apply it to real patients. CMs have been adapted also to Team-based Learning (TBL): Knollmann-Ritschel and Durning (2015) replaced an individual assessment using multiple-choice questions (MCQs) with CMs, as well as combined the group assessment and application exercise, whereby teams created CMs. In this study, it was concluded that CMs could provide a means of understanding students' difficulties, misconceptions, and comprehension of the topic that multiple-choice questionnaires wouldn't offer. On the other hand, other studies are comparing the concomitant use of CMs together with traditional methods, with just traditional methods only (like case-based teaching or theoretical lectures), mainly showing no change or improvement of scores in quizzes and exams (Kumar et al., 2011).

Assessing students' knowledge and providing feedback. A concept map constructed by a student should be like a mirror of his/her knowledge and understanding of a topic (Watson, 1989; Durning et al., 2015). Detecting mistakes or misunderstandings by other students or by the teacher and giving proper feedback is a way of promoting a reflection on the topic or question (Mahler et al., 1991) and allowing for studying and discussion to solve those mistakes. Since CMs reflect students' knowledge acquisition, they can be used to assess students' prior understanding of a topic to organize classes and learning material (Simelane et al., 2021), therefore ensuring that students can make sense of the new teaching and learning materials they receive (Hay et al., 2008). This also provides a way of tracking the development of the student's knowledge (Hay et al., 2008; West et al., 2002); namely, students' critical thinking changes in blended learning during clinical clerkships (Silva Ezequiel et al., 2019), and the increased complexity of the map by further corrections and experience with the tool (Slieman & Camarata, 2019; Wu et al., 2016). Some studies described correlations between the scores from student maps and basic science test scores (Fonseca et al., 2020b; Bhusnurmath et al., 2017), differential diagnoses using clinical cases (Wu et al., 2014), or virtual patient systems (Id et al., 2018), clinical courses, or even standardized exam measures, like USMLE Step 2, namely through MCDs (Ferguson et al., 2020). This may reflect possible evidence that these diagrams can play a role in depicting students' successes or difficulties to integrate basic and clinical sciences. Therefore, concept maps support knowledge acquisition and organization of prior and new knowledge (when used progressively during the semester or in an exercise) (Torre et al., 2013), thus providing an alternative to assessment in addition to traditional MCQs (Knollmann-Ritschel & Durning, 2015). The need to use different assessment approaches was pointed out by Durning et al. (2015), who valued CMs importance in the assessment of clinical reasoning due to their capacity to display nonlinear relations to explain concepts.

There is no standard method for the evaluation of CMs and this is well demonstrated by reviewing different methods described in the literature: indirect methods: quantitative pathfinder method (McGaghie, 1996; McGaghie et al., 2000; McGaghie et al., 2004) or direct methods such as the structural scoring based on Novak et al. (1984) and Durning et al. (2015); the relational scoring by Kinchin et al. (2000) and Torre et al. (2013); qualitative method involving trained raters (West et al., 2000; Schmidt, 2006) or a mixed qualitative and quantitative scoring proposed by Fonseca et al. (2020b) In addition, tools like Concept Map Assessment (CMA) from West et al. (2000) and the modified version from Kassab et al. (2016) can evaluate how students or residents organize their reasoning in a way that traditional tests cannot. They can be used to correlate scores from CMs and Script Concordance Tests, creating a way to evaluate students' clinical reasoning (Radwan et al., 2019). These tools have a moderate to strong

interrater reliability, greater in post-instruction maps (West et al., 2000), and can help to explain the cases of students who score well on written MCQ exams, but fail to apply their knowledge in clinical situations (Durning, 2015). This can be associated with the lack of correlation between performance on MCQs and the efficacy of CMs in some studies (Brondfield et al., 2021; González et al., 2008; West et al., 2000). However, there is opposing evidence that describes a significant correlation between the quality of concept maps and the scores on clinical vignette-based problem-solving MCQs examinations, namely in the learning of disciplines such as Pathology, Biochemistry, and Infectious Diseases (Sargolzaie et al., 2019; Baig et al., 2016). After identifying students' misunderstandings, teachers can give feedback regarding those mistakes, helping to clarify the student about the topic; therefore, maps are a bridge of communication between students and teachers. Even group-level feedback given to a group of students that constructed a map together seems to significantly impact individual students (Camarata & Slieman, 2020). Besides, if expert concept maps are given to students to compare to their maps in a fill-in-the-blank exercise using scaffold maps, it also creates an opportunity to obtain feedback about the student's perception of the topic, creating another moment of learning. To improve the understanding of complex disease conditions, such as respiratory failure, medical residents were exposed to concept maps constructed by experts to be used as advance organizers connecting prior knowledge to new information in a study that included a control group who received traditional didactic teaching (Cutrer et al., 2011). Although both groups had access to "expert control maps", the experimental one for the didactic session and the control just as an example, the use of a concept map as an advanced organizer was more evident in the first group, improving better integration of knowledge which persisted after one week. This pattern was also more evident in senior residents. This increased use of expert maps in medical education will be addressed below. However, this trend should not be confused with the use of knowledge maps, which are also graphic organizers which use a common set of links to connect the nodes. Knowledge maps can also be built as scaffolds, allowing for comparisons between self and expert-generated maps (O'Donnell et al., 2002). One example of this theory applied is a recent online tool called UNSW Knowledge Maps. For every activity within this online tool, the teacher must develop an "expert map", which is then linked to a "scaffold map". This "scaffold map" is what students receive as a starting point. The basis of the feedback that UNSW Knowledge Maps generate is a comparison of the propositions found within the student's attempt to match the propositions in the "expert map" (Ho & Velan, 2016; Ho & Velan, 2017). This kind of tool with automated assessment and feedback appears to be a useful addition to the current options of assessment items for both formative and summative purposes (Ho et al., 2018), being an interesting alternative to the use of scaffold maps with automated feedback using Questionmark PerceptionTM (Questionmark Computing Ltd, London, UK) described in another study by the same author (Ho et al., 2014). The use of scaffolds is also described in many other different studies (Rendas et al., 2006; Kumar et al., 2011), namely those using MCDs (Id et al., 2018; Hege et al., 2017). Additional contribution on this topic was developed by Camarata and Slieman (2020) who demonstrated, as a follow-up of their initial work mentioned above, the positive effects of feedback training as a peer review methodology in first-year medical students using CMs. Another approach towards promoting peer review feedback amongst medical students was described by Richards et al. (2013), using CMs in Clinical Physiology Grand Rounds, to highlight attitudes and perceptions between preclinical and clinical students.

4.1.4. Organizing teaching and medical curricula

CMs can also be used by specialized groups of academics to brainstorm, reflect and organize a medical curriculum, namely regarding learning outcomes (Watson, 1989; Hynes et al., 2015; Sieben et al., 2021). For instance, when creating a CM that involves topics from different curricular units or domains, the users can find relationships between the most essential concepts represented. They can therefore reflect on ways to create interdisciplinary activities that integrate multiple concepts from different courses (Daley et al., 2016). This exercise also allows curriculum organizers to find a repetition of concepts among various curricular units, or missing ones that would be relevant to include (Daley et al., 2016), or even subjects that should be more present in the curricula – like what was done in the VU University Medical Centre in Amsterdam regarding the subject of Geriatrics (Meiboom et al., 2018). Open-ended CMs can also be used to brainstorm about quality improvement in the medical curricula, organizing ideas into clusters (Smith et al., 2019). The diagrams constructed can be easily made available to faculty and can be also a helpful tool to present the objectives of curricular units to students at the beginning of the semester, serving as a blueprint for developing curricular goals and learning objectives during classes (Weiss & Levison, 2000). They can also serve as a means to share the teacher's learning strategies (Watson, 1989), or to debate learning outcomes with the tutor (Sieben et al., 2021).

4.2. Teaching and learning medicine with mind maps

Integrating and recalling knowledge from basic sciences to clinical concepts. MMs use visual orientation to present information and, therefore, help students to recall information in an organized manner. They are used by high-achieving students to better recall and "see the big picture" of particular topics (Abdulghani et al., 2014). In medical education, the benefit of using this tool is that it enables medical students, who have to deal with substantial amounts of information, to use a new learning option to integrate all the information they receive and, thus, help them retain it (Vilela et al., 2013). The use of pictures and colors, together with words, appears to combine two different cortical skills that enhance intellectual power and facilitate the conversion of information from short- to long-term memory (Day & Bellezza, 1983). Research suggests that MM improves long-term memory in medical students. A study by Farrand et al. (2002) compared two groups of medical students that had to study a 600-word passage and take a test about it afterward; one of the groups used a self-study technique that they could choose, and the other used mind maps. After a week of learning this tool, the factual knowledge was greater in the mind map group, implying that the use of MMs improves cognitive processing, therefore being a tool that can improve students' academic performance (Farrand et al., 2002). In addition, teaching anatomy with MM-based PowerPoint slides can also improve learning (Abdolahi et al., 2011).

Regarding the role of MMs in clinical teaching, it is shown that these tools are useful to organize information on a clinical topic, either for students, medical teams, or patients, both for diagnosis and treatment (Mollberg & Salgia, 2011). As for better improving the understanding of relations between basic and clinical concepts, it was found that MMs can play a role in the organization of "the big picture" (Srinivasan et al., 2008). However, this approach can only be used in the broad sense since MMs don't include linking words, and therefore the relationship between concepts is not truly expressed.

Organizing students' learning process (individually and in groups) and helping review topics. The MM technique can be easily taught and learned and requires no equipment or high costs (D'Antoni et al., 2010). Besides, it is very versatile in the sense that the teacher can use the same MM in the preparation of lectures or shorter presentations, as a lecture material (replacing PowerPoint slides) (Abdolahi et al., 2011; Johnson, 2014) and/or have them delivered to the students during the session. These maps organize content into many topics, increasing the level of detail and decreasing generalization, serving as a base for the content sequencing required for planning to teach (Farrand et al., 2002). When studying individually, students can also use MMs for study planning, assessing their learning topic by topic, and planning their efforts based on the key objectives and needs identified in the curricula (Vilela et al., 2013). MMs are also considered user-friendly, and students perceive MMs constructed during a class or at home as study material for further revision of the subject or even updating the map with new information so that students can quickly reactivate their learning (Edwards & Cooper, 2010). In a study by Wickramasinghe et al. (2007), medical students considered MMs helpful in summarizing and memorizing information, showing interest in learning more about this technique to use in their future academic activities (Wickramasinghe et al., 2007).

Assessing students' knowledge including the support for clinical reasoning development in general practice. A MM created by a student can show possible misconceptions regarding mistakes in the inclusion of content. There are not many studies regarding using this tool for student assessment in medical school, but there are some attempts to use them similarly to CMs. One example is the Mind Map Assessment Rubric (MMAR) (D'Antoni et al., 2009), which is a method of scoring MMs adapted from a CMs' assessment scoring system, including concept-links, cross-links, hierarchies, examples, pictures, and colors. This tool was considered valid to detect changes in knowledge among medical students, but further reliability studies are required on this topic. Another example is the use of MMs in the assessment of clinical reasoning of general practice (GP) trainees. Kibble et al. (2014) used the method from Fish and de Cossart (2007) to categorize components of trainees' MMs under the heading of "Clinical Reasoning" and "Deliberation", to assess their thinking about a clinical case during their GP training. They analyzed MMs constructed four months apart and concluded that the trainees' experience provided more complex and complete reasoning, more significantly in the "Deliberation" components, which included competencies in the management of patients inside the biopsychosocial model. Therefore, MMs can provide a unique view of the resident's clinical reasoning development during their training (Kibble et al., 2014). Another tool such as the Global Assessment of Reflection Ability (GAR) was developed based on MMs, to foster the reflection ability of trainees during their GP training (Lillevang et al., 2020). Scaffolded MMs may also be used for the assessment of residents in the context of clinical practice and seem to bring good results compared to MCQ exams (Cruza & Fierros, 2006).

5. Conclusion

The use of mapping in medicine goes well beyond education and training. However, our review was focused on these areas and allowed us to have a broad perspective of its potential, including its use with other methodologies such as PBL, CBL, and TBL. The display of acquired knowledge given by concept mapping allows for improving collaborative learning. Its approach to multi- and interdisciplinary training is essential to improve health care based on teamwork.

Preliminary analysis points to the lack of standardization in most of the information available both in the building and utilization of the maps. However, the articles on CMs were the great majority and with a more homogeneous structure following the rules defined by Novak's group, as a standard methodology. In some of these articles the Novakian rules were mentioned in the methodology but not fully applied. These findings were common to all the articles, from undergraduate medical education to clinical training.

At this stage of our work, we consider that the use of mapping in medical education is important considering, in each case, the context in which teaching and learning occur and if the visual mapping complements other educational strategies. In every case, a standard methodology of map building and use should be displayed preferably using Novakian rules.

Author Statement

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West, D. C., Park, J. K., Pomeroy, J. R., & Sandoval, J. (2002). Concept mapping assessment in medical education: A comparison of two scoring systems. *Medical Education*, *36*(9), 820–826. https://doi.org/10.1046/j.1365-2923.2002.01292.x

West, D. C., Pomeroy, J. R., Park, J. K., Gerstenberger, E. A., & Sandoval, J. (2000). Critical thinking in graduate medical education: A role for concept mapping assessment? *JAMA*, *284*(9): 1105. https://doi.org/10.1001/jama.284.9.1105

Wickramasinghe, A., Widanapathirana, N., Kuruppu, O., Liyanage, I., & Karunathilake, I. (2007). Effectiveness of mind maps as a learning tool for medical students. *South-East Asian Journal of Medical Education*, *1*(1), 30–32.

https://doi.org/10.4038/seajme.v1i1.506

Wu, B., Wang, M., Grotzer, T. A., Liu, J., & Johnson, J. M. (2016). Visualizing complex processes using a cognitive-mapping tool to support the learning of clinical reasoning. *BMC Medical Education*, *16*(1): 216. https://doi.org/10.1186/s12909-016-0734-x

Wu, B., Wang, M., Johnson, J. M., & Grotzer, T. A. (2014). Improving the learning of clinical reasoning through computer-based cognitive representation. *Medical Education Online*, *19*(1): 25940. https://doi.org/10.3402/meo.v19.25940

Appendix I

Articles included in the scoping review

Articles – Concept Maps' search	Year	University/ College/Country
Brondfield S, Seol A, Hyland K, Teherani A, Hsu G. Integrating Concept Maps into a Medical Student Oncology Curriculum. J Cancer Educ. 2021 Feb;36(1):85-91. doi: 10.1007/s13187-019-01601-7. PMID: 31414369.	2021	University of California, San Francisco, USA
Choudhari, S.G., Gaidhane, A.M., Desai, P. et al. Applying visual mapping techniques to promote learning in community-based medical education activities. BMC Med Educ 21, 210 (2021). https://doi.org/10.1186/s12909-021-02646-3	2021	Jawaharlal Nehru Medical College, India
Fonseca, M., Oliveira, B., Canha, I., Dores, H., Santos, M. P., Lemos, V. C., Verdasca, A., Branco, M., Póvoa, A. R., Carreiro-Martins, P., Rendas, A., & Neuparth, N. (2021). Analyzing the use of linking words in concept maps designed for pathophysiology learning in medicine. In HEAd 2021 - 7th International Conference on Higher Education Advances (pp. 95-102). (International Conference on Higher Education Advances). Universidad Politecnica de Valencia.. https://doi.org/10.4995/HEAd21.2021.13036	2021	NOVA University of Lisbon, Portugal
Maryam A, Mohammadreza D, Abdolhussein S, Ghobad R, Javad K. Effect of Concept Mapping Education on Critical Thinking Skills of Medical Students: A Quasi-experimental Study. Ethiop J Health Sci. 2021;31(2):409-418. doi:10.4314/ejhs.v31i2.24	2021	Shiraz University of Medial Sciences, Iran
Nath, Sarmila & Bhattacharyya, Swati & Preetinanda, Pallavi. (2021). Perception of Students and Faculties towards Implementation of Concept Mapping in Pharmacology: A Cross-sectional Interventional Study. JOURNAL OF CLINICAL AND DIAGNOSTIC RESEARCH. 15. 10.7860/JCDR/2021/48561.14797.	2021	Kar Medical College, Kolkata, West Bengal, India
Simelane, T., Ryan, D.J., Stoyanov, S. et al. Bridging the divide between medical school and clinical practice: identification of six key learning outcomes for an undergraduate preparatory course in radiology. Insights Imaging 12, 17 (2021). https://doi.org/10.1186/s13244-021-00971-	2021	Department of Radiology, Cork University Hospital, Wilton, Cork, Ireland
Camarata, Troy & Slieman, Tony. (2020). Improving Student Feedback Quality: A Simple Model Using Peer Review and Feedback Rubrics. Journal of Medical Education and Curricular Development. 7. 238212052093660. 10.1177/2382120520936604.	2020	New York Institute of Technology College of Osteopathic Medicine at Arkansas State University, Jonesboro, AR, USA.
Ferguson KJ, Kreiter CD, Franklin E, Haugen TH, Dee FR. Investigating the validity of web-enabled mechanistic case diagramming scores to assess students' integration of foundational and clinical sciences. Adv Health Sci Educ Theory Pract. 2020 Aug;25(3):629-639. doi: 10.1007/s10459-019-09944-y. Epub 2019 Nov 13. PMID: 31720878.	2020	University of Iowa Carver College of Medicine, Iowa City, IA, USA
Fonseca M, Oliveira B, Carreiro-Martins P, Neuparth N, Rendas A. Revisiting the role of concept mapping in teaching and learning pathophysiology for medical students. Adv Physiol Educ. 2020;44(3):475-481. doi:10.1152/ADVAN.00020.2020	2020	NOVA University of Lisbon, Portugal

Fonseca, M., Oliveira, B., Martins, P., Neuparth, N., & Rendas, A. B. (2020). A score methodology to assess concept maps in medical education in the context of pathophysiology teaching. In HEAd 2020 - 6th International Conference on Higher Education Advances (pp. 867-874). (International Conference on Higher Education Advances; Vol. 2020-June). Universitat Politecnica de Valencia. https://doi.org/10.4995/HEAd20.2020.11163	2020	NOVA University of Lisbon, Portugal
LeClair RJ, Binks AP. Using Near-Peer Teaching to Address Concepts of Cystic Fibrosis in Undergraduate Medical Learners. MedEdPORTAL. 2020 Aug 28;16:10961. doi: 10.15766/mep_2374-8265.10961. PMID: 32875098; PMCID: PMC7453652.	2020	Vanderbilt University School of Medicine, USA
Sieben JM, Heeman S, Verheggen MM, Driessen EW. Can concept mapping support the quality of reflections made by undergraduate medical students? A mixed method study. Med Teach. 2020 Apr; 43(4): 388-396. doi: 10.1080/0142159X.2020.1834081. Epub 2020 Dec 5. PMID: 33280482.	2020	Maastricht University, The Netherlands
Ezequiel OS, Tibiriçá SH, Moutinho ILD, Lucchetti ALG, Lucchetti G, Grosseman S, et al. Medical students' critical thinking assessment with collaborative concept maps in a blended educational strategy. Educ Health 2019;32:127-30 doi: 10.4103/efh.EfH_306_15	2019	Federal University of Juiz de Fora, Brazil
Muthukrishnan SP, Chandran DS, Afreen N, Bir M, Dastidar SG, Jayappa H, Mattoo B, Navneet A, Poorasamy J, Roy A, Sharma A, Ghosh D, Deepak KK. Planning, implementation, and evaluation of multicomponent, case-based learning for first-year Indian medical undergraduates. Adv Physiol Educ. 2019 Dec 1;43(4):504-511. doi: 10.1152/advan.00080.2019. PMID: 31553644.	2019	All India Institute of Medical Sciences, New Delhi, India
Peñuela-Epalza M, De la Hoz K. Incorporation and evaluation of serial concept maps for vertical integration and clinical reasoning in case-based learning tutorials: Perspectives of students beginning clinical medicine. Med Teach. 2019;41(4):433-440. doi:10.1080/0142159X.2018.1487046	2019	Universidad del Norte, Barranquilla, Colombia
Si, J., Kong, H., & Lee, S. (2019). Developing Clinical Reasoning Skills Through Argumentation With the Concept Map Method in Medical Problem-Based Learning. Interdisciplinary Journal of Problem-Based Learning, 13(1). Available at: https://doi.org/10.7771/1541-5015.1776	2019	Dong-A University, Korea
Slieman TA, Camarata T. Case-Based Group Learning Using Concept Maps to Achieve Multiple Educational Objectives and Behavioral Outcomes. J Med Educ Curric Dev. 2019;6:238212051987251. doi:10.1177/2382120519872510	2019	New York Institute of Technology College of Osteopathic Medicine, Jonesboro, AR, USA.
Mukhopadhyay K, Mukherjee S, Dhok A, Chatterjee C, Ghosh J. Use of concept map as a reinforcement tool in undergraduate curriculum: An analytical study. J Adv Med Educ Prof. 2019;7(3):118-122. doi:10.30476/JAMP.2019.74920	2019	ESIC Medical College, Joka, Kolkata, India
Sargolzaie, Narjes & Sargazi, Samaneh & Lotfi, Ghazaleh. (2019). Concept mapping as a tool to improve medical student's learning about rabies surveillance. Journal of Education and Health Promotion. 8. 132. 10.4103/jehp.jehp_132_18.	2019	Isfahan University of Medical Education, Isfahan, Iran
Drareni, N. (2018) Using concept mapping through problem-based learning to enhance lifelong knowledge of pronunciation in risk factors for cardiovascular	2018	University of Blida, Algeria

diseases: Case University of Algiers. Journal of Modern Education Review, ISSN 2155-7993, USA June 2018, Volume 8, No. 6, pp. 458–468 Doi: 10.15341/jmer(2155-7993)/06.08.2018/006		
Joshi U, Vyas S. Assessment of Perception and Effectiveness of Concept Mapping in Learning Epidemiology. Indian J Community Med. 2018;43(1):37-39. doi:10.4103/ijcm.IJCM_375_16	2018	AMC MET Medical College, Ahmedabad, Gujarat, India
Meiboom AA, De Vries H, Scheele F, Hertogh CMPM. Raising enthusiasm for the medical care of elderly patients: A concept mapping study to find elements for an elderly friendly medical curriculum. BMC Med Educ. 2018;18(1):1-9. doi:10.1186/s12909-018-1344-6	2018	VU University Medical Center, Amsterdam. The Netherlands
Radwan A, Abdel Nasser A, El Araby S, Talaat W. Correlation between assessment of concept maps construction and the clinical reasoning ability of final year medical students at the Faculty of Medicine, Suez Canal University, Egypt. Education in Medicine Journal. 2018;10(4):43–51. https://doi.org/10.21315/eimj2018.10.4.5	2018	Faculty of Medicine, Suez Canal University, Egypt
Nicoara, Sergiu & Szabo, Bianca & Micu, Carmen & Badea, Alexandru. (2018). Meta-analysis on the study with concept maps on the medical field. Erdélyi Pszichológiai Szemle. 18. 135-166. 10.24193/epsz.2017.2.4.	2018	Faculty of General Medicine, Cluj-Napoca, Romania
Bhusnurmath SR, Bhusnurmath B, Goyal S, Hafeez S, Abugroun A, Okpe J. Concept map as an adjunct tool to teach pathology. Indian J Pathol Microbiol 2017;60:226-31. DOI: 10.4103/0377-4929.208410	2017	St. George's University, Grenada, West Indies
Dattilo WR, Gagliardi JP, Holmer SA. The Concept of "Concept Mapping" Is Useful in Teaching Residents to Teach. Acad Psychiatry. 2017 Aug;41(4):542-546. doi: 10.1007/s40596-017-0667-7. Epub 2017 Feb 13. PMID: 28194681.	2017	University of Utah, Salt Lake City, UT, USA
Torre D, Daley BJ, Picho K, Durning SJ. Group concept mapping: An approach to explore group knowledge organization and collaborative learning in senior medical students. Med Teach. 2017 Oct;39(10):1051-1056. doi: 10.1080/0142159X.2017.1342030. Epub 2017 Jul 6. PMID: 28681636.	2017	Uniformed Services University of Health Sciences (USUHS), Bethesda, MD, USA
Hege I, Kononowicz AA, Adler M. A Clinical Reasoning Tool for Virtual Patients: Design-Based Research Study. JMIR Med Educ. 2017 Nov 2;3(2): e21. doi: 10.2196/mededu.8100. PMID: 29097355; PMCID: PMC5691243.	2017	University Hospital of LMU Munich, Germany
Hayes MM, Chatterjee S, Schwartzstein RM. Critical Thinking in Critical Care: Five Strategies to Improve Teaching and Learning in the Intensive Care Unit. Ann Am Thorac Soc. 2017 Apr;14(4):569-575. doi: 10.1513/AnnalsATS.201612-1009AS. PMID: 28157389; PMCID: PMC5461985.	2017	Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, USA
Bala S, Dhasmana DC, Kalra J, Kohli S, Sharma T. Role of concept map in teaching general awareness and pharmacotherapy of HIV/AIDS among second professional medical students. Indian J Pharmacol. 2016 Oct;48(Suppl 1): S37-S40. doi: 10.4103/0253-7613.193323. PMID: 28031606; PMCID: PMC5178053.	2016	Department of Pharmacology, HIMS, SRHU, Dehradun, Uttarakhand, India
Ho, V., & Velan, G. (2016). Online concept maps in medical education: Are we there yet? Focus on Health Professional Education, 17(1), 18–29.	2016	University of New South Wales, Australia

https://search.informit.org/doi/10.3316/informit.041438172303834		
Kassab SE, Fida M, Radwan A, Hassan AB, Abu-Hijleh M, O'Connor BP. Generalisability theory analyses of concept mapping assessment scores in a problem-based medical curriculum. Med Educ. 2016;50(7):730-737. doi:10.1111/medu.13054	2016	Faculty of Medicine, Suez Canal University, Egypt
Onyura B, Baker L, Cameron B, Friesen F, Leslie K. Evidence for curricular and instructional design approaches in undergraduate medical education: An umbrella review. Med Teach. 2016;38(2):150-161. doi:10.3109/0142159X.2015.1009019	2016	Centre for Faculty Development, Li Ka Shing Knowledge Institute, Toronto, Canada
Thomas L, Bennett S, Lockyer L. Using concept maps and goal-setting to support the development of self-regulated learning in a problem-based learning curriculum. Med Teach. 2016 Sep;38(9):930-5. doi: 10.3109/0142159X.2015.1132408. Epub 2016 Jan 28. PMID: 26822396.	2016	University of Wollongong, Northfields Drive, Keiraville, NSW, Australia
Vink S, van Tartwijk J, Verloop N, Gosselink M, Driessen E, Bolk J. The articulation of integration of clinical and basic sciences in concept maps: differences between experienced and resident groups. Adv Health Sci Educ Theory Pract. 2016 Aug;21(3):643-57. doi: 10.1007/s10459-015-9657-2. Epub 2015 Dec 21. PMID: 26692262; PMCID: PMC4923103.	2016	Faculty of Social and Behavioural Sciences, Utrecht University, The Netherlands
Baig M, Tariq S, Rehman R, Ali S, Gazzaz ZJ. Concept mapping improves academic performance in problem solving questions in biochemistry subject. Pak J Med Sci. 2016 Jul-Aug;32(4):801-5. doi: 10.12669/pjms.324.10432. PMID: 27648017; PMCID: PMC5017080.	2016	Bahria University Medical and Dental College (BUMDC), Karachi, Pakistan
Wu B, Wang M, Grotzer TA, Liu J, Johnson JM. Visualizing complex processes using a cognitive-mapping tool to support the learning of clinical reasoning. BMC Med Educ. 2016 Aug 22;16(1):216. doi: 10.1186/s12909-016-0734-x. PMID: 27549130; PMCID: PMC4994325.	2016	Faculty of Education, The University of Hong Kong, Hong Kong
Barbara E.C. Knollmann-Ritschel, MC USN, Steven J. Durning, MD, PhD, Using Concept Maps in a Modified Team-Based Learning Exercise, Military Medicine, Volume 180, Issue suppl_4, 1 April 2015, Pages 64–70, https://doi.org/10.7205/MILMED-D-14-00568	2015	University of the Health Sciences, 4301 Jones Bridge Road, Bethesda, USA
Bixler GM, Brown A, Way D, Ledford C, Mahan JD. Collaborative concept mapping and critical thinking in fourth-year medical students. Clin Pediatr (Phila). 2015;54(9):833-839. doi:10.1177/0009922815590223	2015	The Ohio State University, Columbus, OH, USA
Hynes H, Stoyanov S, Drachsler H, et al. Designing Learning Outcomes for Handoff Teaching of Medical Students Using Group Concept Mapping: Findings from a Multicountry European Study. Acad Med. 2015;90(7):988-994. doi:10.1097/ACM.0000000000000642	2015	University College Cork, Ireland
Torre DM, van der Vleuten C, Dolmans D. Theoretical perspectives and applications of group learning in PBL. Med Teach. 2016;38(2):189-95. doi: 10.3109/0142159X.2015.1009429. Epub 2015 Jun 15. PMID: 26075957.	2015	Department of Medicine, Drexel University College of Medicine, Philadelphia, USA
Vink, S.C., Van Tartwijk, J., Bolk, J. et al. Integration of clinical and basic sciences in concept maps: a mixed-method study on teacher learning. BMC Med Educ 15, 20 (2015). https://doi.org/10.1186/s12909-015-0299-0	2015	Faculty of Social and Behavioural Sciences, Utrecht University, The Netherlands

Wong G. Meaningful GP learning with concept mapping. Educ Prim Care. 2012 Jul;23(4):300-7. doi: 10.1080/14739879.2012.11494126. PMID: 22925965.	2015	NHS Salford, North Western Deanery, UK
Ho V, Kumar RK, Velan G. Online testable concept maps: Benefits for learning about the pathogenesis of disease. Med Educ. 2014;48(7):687-697. doi:10.1111/medu.12422	2014	School of Medical Sciences, University of New South Wales, Sydney
Saeidifard F, Heidari K, Foroughi M, Soltani A. Concept mapping as a method to teach an evidence-based educated medical topic: a comparative study in medical students. J Diabetes Metab Disord. 2014 Nov 1;13(1):86. doi: 10.1186/s40200-014-0086-1. PMID: 25419519; PMCID: PMC4241228.	2014	Tehran University of Medical Sciences, Iran
Smith, C. S., Hill, W., Francovich, C., Morris, M., Robbins, B., Robins, L., & Turner, A. (2014). Diagnostic Reasoning across the Medical Education Continuum. Healthcare (Basel, Switzerland), 2(3), 253–271. https://doi.org/10.3390/healthcare2030253	2014	VA Medical Center, Boise, USA
Wu B, Wang M, Johnson JM, Grotzer TA. Improving the learning of clinical reasoning through computer-based cognitive representation. Med Educ Online. 2014;19:25940. Published 2014 Dec 16. doi:10.3402/meo.v19.25940	2014	East China Normal University, Shanghai, China
Krishna Mohan, Surapaneni & Tekian, Ara. (2013). Concept mapping enhances learning of biochemistry. Medical education online. 18. 1-4. 10.3402/meo.v18i0.20157.	2013	Saveetha Medical College and Hospital, India
Richards J, Schwartzstein R, Irish J, Almeida J, Roberts D. Clinical physiology grand rounds. Clin Teach. 2013;10(2):88-93. doi:10.1111/j.1743-498X.2012.00614.x	2013	Beth Israel Deaconess Medical Center, Boston, USA
Torre DM, Durning SJ, Daley BJ. Twelve tips for teaching with concept maps in medical education. Med Teach. 2013;35(3):201-8. doi: 10.3109/0142159X.2013.759644. PMID: 23464896.	2013	Department of Medicine, Drexel University School of Medicine, Philadelphia, PA 19102, USA
Azer SA, Guerrero AP, Walsh A. Enhancing learning approaches: practical tips for students and teachers. Med Teach. 2013 Jun;35(6):433-43. doi: 10.3109/0142159X.2013.775413. Epub 2013 Mar 15. PMID: 23496121.	2013	Department of Medical Education, College of Medicine, King Saud University, Riyadh, Saudi Arabia
Addae JI, Wilson JI, Carrington C. Students' perception of a modified form of PBL using concept mapping. Med Teach. 2012;34(11): e756-62. doi: 10.3109/0142159X.2012.689440. PMID: 23140306	2012	Faculty of Medical Sciences, University of the West Indies, Trinidad and Tobago
Alamro AS, Schofield S. Supporting traditional PBL with online discussion forums: A study from Qassim Medical School. Med Teach. 2012;34(SUPPL. 1). doi:10.3109/0142159X.2012.656751	2012	Qassim Medical School, Saudi Arabia
Cutrer WB, Castro D, Roy KM, Turner TL. Use of an expert concept map as an advance organizer to improve understanding of respiratory failure. Med Teach. 2011;33(12):1018-26. doi: 10.3109/0142159X.2010.531159. PMID: 22225439.	2011	Vanderbilt University School of Medicine, USA
Kumar S, Dee F, Kumar R, Velan G. Benefits of testable concept maps for	2011	University of New South

learning about pathogenesis of disease. Teach Learn Med. 2011 Apr;23(2):137-43. doi: 10.1080/10401334.2011.561700. PMID: 21516600.		Wales, Sydney, Australia
Daley BJ, Torre DM. Concept maps in medical education: an analytical literature review. Med Educ. 2010 May;44(5):440-8. doi: 10.1111/j.1365-2923.2010.03628.x. Epub 2010 Mar 30. PMID: 20374475.	2010	University of Wisconsin - Milwaukee, Milwaukee, Wisconsin, USA
Hege I, Kononowicz AA, Kiesewetter J, Foster-Johnson L (2018) Uncovering the relation between clinical reasoning and diagnostic accuracy – An analysis of learner's clinical reasoning processes in virtual patients PLoS ONE 13(10): e0204900. https://doi.org/10.1371/journal. pone.0204900.	2010	University Hospital of LMU Munich, Germany
Kassab SE, Hussain S. Concept mapping assessment in a problem-based medical curriculum. Med Teach. 2010;32(11):926-931. doi:10.3109/0142159X.2010.497824	2010	Medical University of Bahrain, Bahrain
Longenecker R, Zink T, Florence J. Teaching and learning resilience: building adaptive capacity for rural practice. A report and subsequent analysis of a workshop conducted at the Rural Medical Educators Conference, Savannah, Georgia, May 18, 2010. J Rural Health. 2012 Spring;28(2):122-7. doi: 10.1111/j.1748-0361.2011.00376.x. Epub 2011 Apr 27. PMID: 22458312.	2010	Ohio State University, USA
Pottier P, Hardouin JB, Hodges BD, Pistorius MA, Connault J, Durant C, Clairand R, Sebille V, Barrier JH, Planchon B. Exploring how students think: a new method combining think-aloud and concept mapping protocols. Med Educ. 2010 Sep;44(9):926-935. doi: 10.1111/j.1365-2923.2010.03748.x. PMID: 20716103.	2010	Department of Internal Medicine, Nantes University Hospital Centre, Nantes, France
Durning SJ, Lubarsky S, Torre D, Dory V, Holmboe E. Considering "Nonlinearity" Across the Continuum in Medical Education Assessment: Supporting Theory, Practice, and Future Research Directions. J Contin Educ Health Prof. 2015 Summer;35(3):232-43. doi: 10.1002/chp.21298. PMID: 26378429.	2008	Association for Hospital Medical Education (AHME, USA)
Hay, David & Kehoe, Caroline & Miquel, Marc & Hatzipanagos, Stylianos & Kinchin, Ian & Keevil, Steve & Lygo-Baker, Simon. (2008). Measuring the quality of e-learning. British Journal of Educational Technology. 39. 1037 - 1056. 10.1111/j.1267-	2008	King's College London, UK
Srinivasan M, Mcelvany M, Shay JM, Shavelson RJ, West DC. Measuring Knowledge Structure: Reliability of Concept Mapping Assessment in Medical Education. 2008;83(12):1196-120 DOI: 10.1097/ACM.0b013e31818c6e84	2008	University of California-Davis School of Medicine, USA
González HL, Pardo Palencia A, Alfredo Umaña L, Galindo L, Villafrade M LA. Mediated learning experience and concept maps: a pedagogical tool for achieving meaningful learning in medical physiology students. Am J Physiol - Adv Physiol Educ. 2008;32(4):312-316. doi:10.1152/advan.00021.2007	2008	Universidad Autónoma de Bucaramanga, Colombia
Kinchin, Ian & Cabot, Lyndon & Hay, David. (2008). Using concept mapping to locate the tacit dimension of clinical expertise: Towards a theoretical framework to support critical reflection on teaching. Learning in Health and Social Care. 7. 93 - 104. 10.1111/j.1473-6861.2008.00174.x.	2008	King's College London, UK
Torre DM, Daley B, Stark-Schweitzer T, Siddartha S, Petkova J, Ziebert M. A qualitative evaluation of medical student learning with concept maps. Med	2007	Medical College of Wisconsin, Milwaukee, USA

Teach. 2007 Nov;29(9):949-55. doi: 10.1080/01421590701689506. PMID: 18158670.		
Rendas AB, Fonseca M, Pinto PR. Toward meaningful learning in undergraduate medical education using concept maps in a PBL pathophysiology course. Adv Physiol Educ. 2006 Mar;30(1):23-9. doi: 10.1152/advan.00036.2005. PMID: 16481605.	2006	NOVA University of Lisbon, Portugal
Schmidt HJ. Alternative approaches to concept mapping and implications for medical education: Commentary on reliability, validity and future research directions. Adv Heal Sci Educ. 2006;11(1):69-76. doi:10.1007/s10459-004-4813-0	2006	Columbia University, College of Physicians and Surgeons, NY
McGaghie, W.C., McCrimmon, D.R., Mitchell, G. et al. Concept Mapping in Pulmonary Physiology Using Pathfinder Scaling. Adv Health Sci Educ Theory Pract 9, 225–240 (2004). https://doi.org/10.1023/B:AHSE.0000038299.79574.e8	2004	The Feinberg School of Medicine, Northwestern University, Chicago, USA
Hoffman E, Trott J, Neely KP. Concept mapping: a tool to bridge the disciplinary divide. Am J Obstet Gynecol. 2002 Sep;187(3 Suppl): S41-3. doi: 10.1067/mob.2002.127360. PMID: 12235440.	2002	American College of Women's Health Physicians, USA
West DC, Park JK, Pomeroy JR, Sandoval J. Concept mapping assessment in medical education: A comparison of two scoring systems. Med Educ. 2002;36(9):820-826. doi:10.1046/j.1365-2923.2002.01292.x	2002	School of Medicine, University of California, USA
McGaghie WC, McCrimmon DR, Mitchell G, Thompson JA, Ravitch MM. Quantitative concept mapping in pulmonary physiology: comparison of student and faculty knowledge structures. Adv Physiol Educ. 2000 Jun;23(1):72-81. doi: 10.1152/advances.2000.23.1.S72. PMID: 10902530.	2000	Northwestern University Medical School, Chicago, Illinois, USA
Weiss LB, Levison SP, Donoghue GD, Hoffman E, Magrane D. Tools for integrating women's health into medical education: Clinical cases and concept mapping. Acad Med. 2000;75(11):1081-1086. doi:10.1097/00001888-200011000-00012	2000	MCP Hahnemann School of Medicine, Pennsylvania, USA
West DC, Pomeroy JR, Park JK, Gerstenberger EA, Sandoval J. Critical thinking in graduate medical education: A role for concept mapping assessment? J Am Med Assoc. 2000;284(9):1105-1110. doi:10.1001/jama.284.9.1105	2000	University of California, USA
Pinto AJ, Zeitz HJ. Concept mapping: A strategy for promoting meaningful learning in medical education. Med Teach. 1997;19(2):114-121. doi:10.3109/01421599709019363	1997	Allegheny University of the Health Sciences, Philadelphia, USA
McGaghie, WC. Comparison of Knowledge Structures with the Pathfinder Scaling Algorithm. Apr 96 18p.; Paper presented at the Annual Meeting of the American Educational Research Association (New York, NY, April 8-12, 1996).	1996	Northwestern University Medical School, USA
Mahler, S., Hoz, R., Fischl, D., Tov-Ly, E., & Lernau, O. Z. (1991). Didactic use of concept mapping in higher education: applications in medical education. Instructional Science, 20(1), 25–47. http://www.jstor.org/stable/23369886	1991	Ben-Gurion University of the Negev, Israel
Watson GR. What is . . . concept mapping? Med Teach. 1989;11(3-4):265-9.	1989	Centre of Medical Education,

doi: 10.3109/01421598909146411. PMID: 2640685.		University of Dundee, Scotland, UK
Small PA Jr. Consequences for medical education of problem-solving in science and medicine. J Med Educ. 1988 Nov;63(11):848-53. doi: 10.1097/00001888-198811000-00004. PMID: 3184150.	1988	University of Florida, College of Medicine, USA
Articles – Knowledge Maps' search	**Year**	**University/ College/Country**
Ho VW, Harris PG, Kumar RK, Velan GM. Knowledge maps: a tool for online assessment with automated feedback. Med Educ Online. 2018 Dec;23(1):1457394. doi: 10.1080/10872981.2018.1457394. PMID: 29608133; PMCID: PMC5907351.	2019	Faculty of Medicine, UNSW Sydney, Australia
Ho V, Velan G. Unsw Knowledge Maps: an Online Tool for Knowledge Mapping With Automated Feedback. EDULEARN17 Proceedings. 2017;1(July):7660-7667. doi:10.21125/edulearn.2017.0392	2017	Faculty of Medicine, UNSW Sydney, Australia
Articles – Mind Maps' search	**Year**	**University/ College/Country**
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