Revisiting the role of concept mapping in teaching and learning pathophysiology for medical students

Marta Fonseca, Beatriz Oliveira, Pedro Carreiro-Martins, Nuno Neuparth, and António Rendas

Introduction

Concept mapping methodology is a way of representing knowledge described as a useful tool in medical education. It was introduced in the pathophysiology curricular unit at NOVA Medical School in 2002, within an ongoing experience of problem-based learning. Our goal is to present a comparison between the students’ opinions and performances in two academic years, 2017–2018 and 2018–2019, to evaluate the effects of pedagogical changes in the concept mapping methodology, applied in the last year, which is also described in detail. Our convenience samples were composed by 224 students in 2017–2018 and by 216 students in 2018–2019. The analysis used the students’ responses to the yearly institutional questionnaire on the quality of teaching and to a specific questionnaire applied to evaluate the tutorial sessions of 2018–19. Both were anonymous, and the response rate was above 50%. A comparison was also made between the continuous assessment during the tutorial sessions, expressed as a final cumulative score, and the results of an obligatory multiple-choice final test. The students considered the introduced pedagogical changes useful in their different components, such as identification of core concepts, construction of mini-maps, and their inclusion in final global maps. The better performance of the tutors, signaled by the students in 2018–19, was probably due to the preparatory pedagogical sessions.

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INTRODUCTION

Concept mapping methodology is a way of representing knowledge integrated into a network of concepts (15, 16). This methodology can also illustrate how students integrate new information into their preexisting knowledge. In a recent scoping review of the use of concept maps (CMs) in medical education, it is clearly demonstrated the importance of this methodology in three areas: linking basic sciences and clinical practice, developing clinical reasoning, and interprofessional and group learning (4).

The discipline of pathophysiology has been taught at NOVA Medical School (NMS) since 1982 (14) and pioneered in Portugal the introduction of problem-based learning (PBL) in an undergraduate 6-yr medical curriculum, as described by our group in the late 90’s and in the first decade of this century (2, 3). The CM methodology was introduced in 2002, as an additional education methodology, allowing for the visual display of pathophysiology learning during the analyses of the PBL cases (17). We have demonstrated that CM methodology stimulates the learning of pathophysiological concepts and facilitates the dynamics of tutorial sessions (17). The main purpose was to improve meaningful learning of pathophysiological mechanisms, in the context of clinical cases, based on which the students, working in small groups, produced CMs that were then presented and discussed by the whole tutorial group. Since this CM methodology was applied to the whole class of students, divided into multiple tutorials groups, it was not possible to study its effects on the teaching/learning process, because a control group was lacking. In 2012, a major curricular reform occurred at NMS, which organized all of the curricular units in semesters to better comply with the principles of the Bologna process, fully applied in European higher education. Pathophysiology, changed from annual to semestral, and it was moved from the third to the second year of the curriculum, together with histopathology and general pharmacology. Taking into account our previous experience with PBL and CMs, the coordinator of the discipline and the academic staff took the option to maintain the tutorial session model. However, because of time limitations, the PBL cases were replaced by clinical vignettes, with less patient information, given as a whole in the first tutorial session, as a trigger to the learning process related to the study of pathophysiological mechanisms. In the academic year of 2018–19, it was decided to reorganize the methodology of the tutorial sessions, reviewing the use of CMs without any change in the previous syllabus. The main reason for this review came from the feedback from the students of the previous years, namely 2017–2018, expressed in the anonymous, written responses to a standardized questionnaire, which is a part of the institutional policy of NMS to evaluate the quality teaching. The following are examples of students’ comments: “The final map is presented to the whole tutorial group and the tutor discusses it without providing guidelines for the debate”; “The tutor gives no feedback to the students’ performance during the intermediate sessions”; “The evaluation criteria for the intermediate tutorial sessions were not explained to the students”; “The tutor does not explain clearly how the maps are constructed and what content should be included”; “Constructing maps is not the best way to evaluate students.”

The purpose of this article is to present the comparison between the students’ comments and performances, in two successive academic years 2017–2018 and 2018–2019, to...
study the effects of the newly introduced pedagogical changes on the teaching/learning process.

**MATERIAL AND METHODS**

General information. In the academic years of 2017–2018 and 2018–2019, the pathophysiology curricular unit was composed of lectures, covering the total theoretical content of the discipline, and tutorial sessions using CMs, based on an organ/body system curriculum, covering the following five blocks: digestion, respiration, circulation, renal and body fluids, and the endocrine system. The reference book recommended was *Pathophysiology of Disease: An Introduction to Clinical Medicine* (9).

In 2017–18, the dynamics of the tutorial sessions were as follows: each organ/system block lasted for five sessions, during which the students analyzed two clinical vignettes, one lasting two sessions and the other three. Two maps were produced per block: the former simpler, involving one or two concepts, and then the latter, which included more than three concepts. The students received written information concerning the evaluation criteria, which covered the following items: active participation in the tutorial sessions (questioning and commenting), involvement in the insertion of new information in the maps, and construction of the map (organization and content). The continuous assessment of the students’ performance by the tutor occurred during all of the sessions and was converted into a final score, represented on a scale ranging from 0 to 10, which contributed 50% to the final mark of each student. The other 50% came from the score of the final multiple-choice questions (MCQ) test related to the content of the discipline. The class of 2017–2018 was composed of 224 newly enrolled students, divided into 18 tutorial groups, ranging in size between 6 and 15 students.

In 2018–19, the dynamics of the tutorial sessions were as follows: each organ/system block lasted for four sessions, during which the students analyzed one clinical vignette, based on the “longer” vignette of 2017–18, with specific adaptations related to the core concepts, as will be described below. As in the previous year, a written document was given to the students, but, in addition, it contained detailed information concerning the dynamics of the sessions and the evaluation criteria of the architecture of the final map, divided in 1) qualitative, such as the inclusion of all of the patient information and a legend, and 2) quantitative, such as the use of propositions, the existence of a hierarchical organization of the concepts, the presence of horizontal links, and the inclusion of examples. All of the other evaluation criteria were similar to the previous year, with the additional emphasis on the identification of the core concepts, its explanations in the mini-maps, and their inclusion in the final map. The continuous (time-distributed) assessment of the students’ performance by the tutor occurred during all of the sessions and was converted into a final score, represented on a scale ranging from 0 to 10, which contributed 50% to the final mark of each student. The other 50% came from the score of the final MCQ test related to the content of the discipline. The class of 2018–2019 was composed of 216 newly enrolled students and was divided also into 18 tutorial groups, ranging in size between 7 and 16 students.

The students installed the freely available software program Cmap tools (IHMC Cmap Tools, Florida) and were shown how to use it. After the first session, in each block, the students, working in small groups, improved the CMs, based on learning issues identified during self-learning, which occurred between the tutorials. In the last session of the block, the students presented a final CM for discussion, involving the whole group.

Pedagogical changes introduced in the academic year 2018–2019. According to the feedback given by the students in the questionnaire of NMS institutional policy for the quality evaluation of teaching, the pedagogical methodologies were reviewed in the academic year 2018–2019. The main steps introduced were a preparatory training period for the tutors, schematized in Fig. 1, and a revision of CMs’ methodology, including its construction, presentation, discussion, and assessment criteria. A core group was created, involving the course director, the two most senior faculty members, a junior faculty member experienced in concept mapping, and a medical student from the previous year, who acted both individually but also as informal speaker of the students’ positions stated in the questionnaire from 2017 to 2018.

In the formative pedagogical training sessions, developed for the staff, eight core concepts were identified, for each clinical vignette, which are listed in Fig. 2. These core concepts were used to construct mini-maps during the tutorial sessions. In each of the five blocks, the students constructed eight mini-maps, which were reorganized into a final CM (Fig. 3 and Suplemental Figs. S1–S4). All Supplemental Figures are available at https://doi.org/10.6084/m9.figshare.12315119.v1, which was presented and discussed in the final session of each block.

These activities were approved by the Pedagogical Council of NMS, which is the board responsible, legally, for regulating all of the academic procedures. It includes representatives of medical students. How the changes were assessed. To compare the comments and students’ performances in the two successive academic years 2017–2018 and 2018–2019, we considered three parameters.

The first parameter was based on the response to the already mentioned institutional standardized questionnaire, comparing

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*Fig. 1. Pedagogical training sessions organized to prepare the teaching staff for the academic year of 2018–2019. CM, concept map.*

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both academic years. It was voluntary, anonymous, and part of the institutional policy of NMS for the quality evaluating of teaching.

The second parameter was based on the response to a newly developed questionnaire for the curricular unit, also voluntary and anonymous, applied to the students of the academic year of 2018–2019, in the midterm of the semester.

Finally, the third parameter was based on the comparison between the final summative assessment and the multiple-choice test scores (MedQuizz) in the two sequential years, both on a 0–10 scale.

**Statistical analysis.** We worked with convenience samples, corresponding to the pathophysiology students of the above-mentioned 2 consecutive yr.

An exploratory analysis of the answers to the institutional questionnaire, addressing the quality of the educational process, and to the midterm questionnaire was carried out. These questionnaires assessed the opinion of the students using a Likert level scale. The Mann-Whitney test was used to compare the results of the questions to the institutional questionnaire, addressing the quality of the educational process in the 2 sequential yr.

Student’s $t$ test was used on continuous variables. The Pearson correlation was also calculated to evaluate the association between the final tutorial assessment and the multiple-choice test. The level of significance considered was $\alpha = 0.05$. Data analysis was performed using STATA (StataCorp LP, Stata Statistical Software, release 12, TX).

**RESULTS**

**Institutional questionnaire.** The institutional questionnaire of NMS was completed by 143 students in the academic year of 2017–18 and by 122 in the academic year of 2018–19. Table 1 shows the comparison between the 2 yr, illustrating that the scores of the standard tasks performed by faculty, also voluntary and anonymous, applied to the students of the academic year of 2018–2019, in the midterm of the semester.

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Midterm questionnaire applied in 2018–2019. Concerning the questionnaire distributed to the students about the use of core concepts in the construction of the mini-maps and the architecture of the global maps, the majority of the students agreed or strongly agreed with all the items. The best score was obtained in the second question, for which 95.6% of the students considered that CMs allowed the establishment of an orderly relation between core concepts. The worst result was obtained in the last question, for which only 70% of the students considered that the use of CMs added value to pathophysiology learning (Table 2).

Final summative assessment and multiple-choice test. The results of the students’ performance in the 2 academic yr showed that, despite an improvement in the scores, both of the final summative assessment and in the final MedQuizz test, between the 2 yr (Table 3), the differences between years did not reach statistical significance ($P$ value $= 0.595$). However, the correlation coefficient was higher in the academic year of 2018–2019 ($r = 0.293$; year 2, $r = 0.446$).

**DISCUSSION**

The present study describes how CMs can be part of the teaching and learning methods used in a complete curricular unit of pathophysiology designed for medical students. The main conclusion is that such innovation, although successful, required appropriate preparation and continuous follow-up, involving teachers and students. Despite the considerable experience of our group using CMs in pathophysiology, including in PBL settings, the option taken to review the training of the tutors, the design of the maps and teaching methods, proved to be useful. This decision took into account the comments, expressed by the students from the class of 2017–2018, related to the role of CMs in the teaching and learning process. As already mentioned, the option of our group to abandon PBL methodology was due to a significant reduction in the number of tutorial sessions, which occurred in 2012, when the pathophysiology course changed from annual to a single semester, due to the institutional curricular reform. Since that year, the pathophysiology curriculum addressed only the major syndromes...
Table 1. Comparison between the responses to the institutional questionnaire addressing the quality of the educational process in the two sequential years of 2017–2018 and 2018–2019

| Questions | Year 1 Median (P25–P75) | Year 2 Median (P25–P75) | P Value |
|-----------|------------------------|------------------------|---------|
| Q1. I understood the contents of the curricular unit. | 3 (3–4) | 3 (3–3) | 0.364 |
| Q2. The objectives were clearly explained by the teacher. | 3 (3–4) | 3 (3–4) | 0.607 |
| Q3. I think I have achieved the desired goals. | 5 (4–5) | 5 (4–5) | 0.454 |
| Q4. The teaching methodologies used contributed to my learning. | 4 (3–5) | 5 (4–5) | <0.001* |
| Q5. The resources available have contributed to my learning. | 4.5 (4–5) | 5 (4–5) | <0.001* |
| Q6. I was informed about the evaluation criteria. | 5 (5–5) | 5 (5–5) | 0.159 |
| Q7. The proposed evaluation criteria were respected. | 5 (5–5) | 5 (5–5) | 0.417 |
| Q8. Throughout the semester, I was informed about my progress. | 5 (4–5) | 5 (4–5) | 0.045* |
| Q9. Overall, this curricular unit satisfied me. | 5 (4–5) | 5 (4–5) | 0.053 |
| Q10. How much did you attend classes at this course? | 3 (2–3) | 3 (2–3) | 0.290 |
| Q11. How do you evaluate the theoretical teaching of this curricular unit? | 2 (2–3) | 2 (2–3) | 0.179 |
| Q12. How do you evaluate the follow-up of the practical classes? | 3 (2–3) | 3 (2–3) | 0.005* |
| Q13. Do you consider that the evaluation criteria related to practical teaching have been correctly explained? | 3 (2–3) | 3 (2–3) | 0.005* |
| Q14. The final evaluation focused on the taught content and the learning objectives listed in the curricular sheet of the curricular unit. | 3 (2–3) | 3 (2–3) | 0.969 |
| Q15. It identified the theoretical and practical knowledge necessary for the study of this curricular unit that were not previously taught (prerequisites). | 1 (1–1) | 1 (1–1) | 0.548 |

Values are the medians [with the 25th to 75th percentile (P25–P75) in parentheses]; n = 143 students for 2017–2018 (year 1) and n = 122 students for 2018–2019 (year 2). *P < 0.05 (Mann-Whitney test).

The main changes in the CM methodology involving the students in the academic year 2018–2019 were as follows: identification of a fixed number of concepts from the clinical vignettes; progressive building of mini-maps, each one related to a specific concept; and construction of the final CM, as exemplified in Fig. 3 and Supplemental Figs. S1–S4. In this context, the learning periods occurred during the tutorial sessions and between sessions, involving presentations and discussions for self-directed learning, to build the CMs. As for the tutors, the changes were the following: stimulating the debate around the identification of the core concepts, including the identification of learning gaps; accompanying the building of the mini-maps; and assisting in the construction of the final map. The role of the tutors also involved questioning for clarification of preexistent and newly acquired knowledge in the context of the clinical information given in the vignette. The fact that all of the tutors were medically qualified gave a realistic approach to the simulation because they could illustrate features of the clinical conditions with living examples taken from their own clinical experience. The feedback given by the tutors to the students during the tutorial sessions was considered an essential part of the individual learning process. The importance of the tutor’s role has been recently emphasized in case-based and collaborative learning (11).

The clinical vignette was an essential tool of the teaching process, and the option to give all of the patient information in the first session (13), but allowing for further questioning in each organ/system block, using the above-described methodology.

The first analytical review on the use of CMs in medical education (5) proposed that the new developments for the use of CMs should include serial maps and the combination of group CMs with structured feedback. Our study addresses these two issues in the context of a curricular unit given during a whole semester and involving all of the students, in two consecutive academic years. Another essential feature of the present study is related to the nature of the discipline, since the learning of pathophysiology mechanisms involves the integration of basic science knowledge to understand the clinical expressions of different diseases (18) expressed in our settings in the clinical vignettes. In this context, the present study also addresses the challenge identified in a more recent review on CMs (4), as a useful method to relate basic sciences with clinical practice.
related to doubts arising during the self-directed learning period, proved useful to enhance meaningful learning. The same debate occurred during the progressive construction of the final map, starting with mini-maps, based on previously identified core concepts. A similar methodology was used by Addae et al. (1), who developed a five-phase model of PBL with three mapping phases and two phases of questioning formulation, in contrast to the standard seven-step model, and found, based on a student’s questionnaire, higher ratings with the use of the former model concerning the development of metacognitive and interpersonal skills. However, the study failed to evaluate the impact on the academic performance of the students. According to our experience, based on the final multiple-choice test, and comparing these results with the final summative assessment at the end of the tutorial sessions, the differences were not significant, although the students in the academic year of 2018–2019 scored higher, in absolute value, compared with those from the previous year. We also found that, in the year 2018–19, the correlation analysis to assess the association between tutorial assessment and multiple-choice test was higher (year 1, $r = 0.293$; year 2, $r = 0.446$). This suggests that a higher $r$ value in the 2018–19 yr perhaps indicates that the tutor scores are more accurate estimates of student knowledge.

Using online incomplete maps with missing nodes (10) demonstrated, by using a multiple-choice test, that the students, recruited as volunteers for the study, improved learning of concepts related to the pathogenesis of diseases. Based on this finding, it was admitted that the multiple-choice test could have a role in the evaluation of meaningful learning. In our study, we have applied multiple-choice tests developed by our group according to the methodology used at NMS. This approach aims for developing a test using a diversity of questions, ranging from memory to higher-order cognitive skills, which are expected to assess meaningful learning (12). For all of these reasons, the choice of the final instrument to evaluate meaningful learning after applying CMs methodology remains open. One possibility could be embedding a multiple-choice test in a CM, as we have attempted in a limited preliminary study (7).

The training of the tutors was also an important component of the study and one of the key features of our strategy. The responses of the students, given both in the institutional questionnaire and in the midterm questionnaire, confirmed that we have achieved our objectives of promoting the involvement of all of the tutors in the CM methodology. In this context, it is relevant to mention that the students clearly identified the pedagogical improvements, which occurred in 2018–19. These improvements included not only support for the pedagogical sessions before the beginning of the course in 2018–2019, but also the availability of the course director to attend tutorial sessions, if requested by different tutors, to give feedback on the dynamics of the session. This activity occurred frequently in the first 3–4 wk of the course and involved the attendance of 30 tutorial sessions, mainly the initial and, in fewer cases, the final session of the different blocks. The core group also met regularly, at least once a month, to evaluate the progress made and to identify possible problems, which were dealt with by direct contact with tutors and students. A similar strategy for involving the tutors in the teaching and learning process was followed by Veronese et al. (20), who demonstrated that CMs, used in the context of a PBL physiology course, were well accepted by students and faculty, as shown by the coherence found in responses from both groups to interviews and surveys. This study also raised the possibility of using CMs as a tool to bridge the gap between basic sciences and clinical practice and suggested the expanding of CMs to preclinical courses, which is what we did in our study with a focus on pathophysiological mechanisms of main syndromes from different organ/systems.

The option to use the template of a CM based on the software program Cmap tools to build our CMs was based on the acceptance of the methodology developed by Joseph Novak and his team from the Institute for Human and Machine Cognition, as described by Daley et al. (4). However, in the context of medical education, particularly for the teaching and learning of pathophysiology using clinical vignettes, the template used also took into account the mechanistic case diagramming (MCD) methodology, proposed by Guerrero (8), which is a template simpler than CMs because it is unidirectional, from top to bottom of the diagram, without linking words and cross-links.

The MCD was considered relevant in our project because it allowed for the display of the relations between the clinical information and the basic science knowledge required to explain the patient’s expressions of disease (symptoms, signs, and diagnostic tests). The building of the mini-maps and the construction of the final CM always kept the patient problem on the top of the map, as a hypothesis that had to be confirmed or refuted by additional knowledge displayed in the CM, along with the sessions. This allowed the students to move from presenting clinical information to causes and mechanisms (“reverse-thinking”) and the opposite (“forward-thinking”) (8).

This patient-oriented approach is not clearly stated in the traditional CM methodology. For these reasons, we did not use the proposed score criteria to rate the structure of the maps (19). However, both the tutors and the students were informed about the criteria to evaluate the map in the context of the learning process, which occurred during the tutorials. The criteria were divided into 1) qualitative, such as the inclusion of the patient information and a legend; and 2) quantitative, such as the use of propositions, the existence of a hierarchical organization of the concepts, the presence of horizontal links, and the inclusion of examples. The tutors used these criteria to obtain a global perspective of the structure of the map. The inclusion, in the CMs, of the clinical information from a specific patient, obtained from the vignette, was essential as a trigger for the study and understanding of the multiple of other disease expressions that were absent in the initial information about the patient. In this component, as occurs in the MCD methodology, we advocate that CMs should be case driven.

However, we also admit that the use of the traditional CM methodology with linking words and hierarchy is useful for meaningful learning, particularly if sustained by dynamic tutorial sessions with an open debate related to key concepts, which, according to our present experience, were very useful and well accepted by the students.

Conclusion and next steps. The use of CMs is rarely applied to a whole class of students, more than 200, divided into 18 tutorial groups, throughout a complete semester. The present study covered 2 consecutive yr, with a class of similar size each year. The pedagogical changes, introduced in 2018–19, using 2017–19 as a comparison, were favorably evaluated by the students, both at midterm and at the end of the course. The
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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

M.F., P.C.-M., N.N., and A.R. conceived and designed research; M.F., P.C.-M., N.N., and A.R. performed experiments; M.F., B.O., P.C.-M., N.N., and A.R. analyzed data; M.F., B.O., P.C.-M., N.N., and A.R. interpreted results of experiments; M.F., B.O., P.C.-M., N.N., and A.R. prepared figures; M.F., B.O., P.C.-M., N.N., and A.R. drafted manuscript; M.F., B.O., P.C.-M., N.N., and A.R. interpreted results; M.F., B.O., P.C.-M., N.N., and A.R. revised manuscript; M.F., B.O., P.C.-M., N.N., and A.R. approved final version of manuscript.

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