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The quality of first-year dental students' cognitive structures and the factors that influence it

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Abstract

Introduction: In health professions education, it is widely recognised that concept mapping helps students organise their knowledge. This study aimed to investigate the quality of first-year dental students' cognitive structures and the factors that influence it. Two approaches (qualitative and descriptive) to analysing student concept maps are described in this article. The qualitative approach emphasises the distinct morphologies (structures) that are considered to indicate the level of understanding. The descriptive approach provides information on the content's richness in terms of concepts and key concepts.

Materials and Methods: A total of 31 first-year dental students participated in this study. In an introductory session, students drew their first concept map (CM) using Cmaptools software. Then, students created and submitted individualised CMs for four course topics. Qualitative and descriptive approaches to analysing concept maps are valuable because they highlight what students have learned and how they organise and structure knowledge through CMs. To determine students' cognitive structures and explore the evolution of their representations over the four course topics, two examiners analysed the CMs' morphology and content.

Results: Students presented various cognitive structures for the same topic. The quality of concept maps seemed to be influenced by the topic, as well as by familiarisation with making CM.

Conclusion: Concept mapping revealed the organisation of students' knowledge. This study explored the structural (morphology) and content analyses of CMs. The quality of the CMs seems to be affected by the nature of the topic.

KEYWORDS
cognitive structure, concept map, dental education, key concepts, morphology

1 | INTRODUCTION

Concepts learned in the classroom must be well organised and structured to be stored efficiently in memory. The structure of a student's memory, called cognitive structure, reflects the organisation of concepts in memory, which is done through patterns and the relationships that associate concepts with each other.[1,2] As Ausubel suggested, cognitive structures are the critical factor in meaningful learning and retention: 'If existing cognitive structure is clear, stable, and suitably organised, it facilitates

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the learning and retention of new subject matter. If it is unstable, ambiguous, disorganised or chaotically organised, it inhibits learning and retention'.[3]

To operationalise Ausubel's learning theory, Novak and Gowin created concept mapping. A concept map (CM) is a useful tool that promotes meaningful learning and improves a student's critical thinking by encouraging students to manipulate information in depth.[4] They described it as a schematic device for representing a set of concepts as nodes that are connected through links containing linking words to form propositions.[5] These propositions indicate units of meaning that highlight the relationships between concepts. A link that establishes a connection between the concepts from different regions and levels of the map is called a cross-link.[6] This type of link demonstrates in-depth learning and the student's ability to connect spatially distant concepts, which translates into elaborated knowledge.

The literature has defined several morphologies for representing concepts in a two-dimensional plane. Kinchin mentioned the six morphologies that CMs can have. Spoke, network, chain and cyclic maps are the most common forms. But he pointed out two additional forms that are ignored in the literature: 'unreflective and undeveloped structures'.[7] These morphologies are shown in Figure 1.

a. A *spoke structure* represents the branching of concepts around the central concept in a radial format. All subordinate concepts link directly to the key idea but not to each other. This could develop into a network.
b. A *network structure* is a graphical representation with fewer concepts than links. Cross-links are particularly prevalent in this type of morphology. The map is well structured, the concepts are well laid out in space and links are present throughout the CM.
c. In a *chain structure*, the concepts are arranged in a linear sequence. This usually reflects rote learning.
d. A *cycle structure* attempts to have cross-links, but they must be particularly realised with active linking phrases. This morphology reflects complexity in the organisation of concepts that is not necessarily relevant or easy to understand.
e. An *unreflective structure* can be overloaded and confuse several structures at once. As such, it can represent excessively detailed knowledge. This morphology derives from the spoke structure, but is more complex. It can easily evolve into the network structure but the student must select the most important concepts and avoid unnecessary details.
f. An *undeveloped structure* is characterised by a very limited number of concepts and a weakness in or absence of links between concepts. The weakness in terms of concepts makes the map very disaggregated and poor in knowledge.

In addition to morphology, the richness of relevant concepts in a CM also reveals the degree of student understanding. Several decades of research have demonstrated that: 'all knowledge is not of equal value, that some propositions take precedence over others in the knowledge frameworks of experts, and that teachers and students should focus their efforts on those fundamental concepts that are critical to understanding'.[8] In this regard, key concepts have been defined as fundamental concepts necessary for the best understanding of the topic being taught. For some subjects, some key concepts seem particularly problematic for students. CMs would therefore be of great use by highlighting the presence or absence of these key concepts. To capture this, we determined the ratio of key concepts (RKC) present in the student's CM to those expected by the teacher. This ratio can be an indicator of the CM's richness.[9]

Indeed, through its morphology and identification of concepts, a CM gives access to cognitive structure. The cognitive structure becomes visible, and the student can easily identify and rectify conceptual gaps or errors. The correspondence between the characteristics of the cognitive structure and the structure of a CM, linking different concepts to form a network, makes it a tool with important pedagogical potential.[10]

Findings in dental education suggest that CMs help students develop a deep understanding that facilitates the acquisition of expertise in problem-solving and decision-making.[11] In Gil's study, concept mapping was a complementary learning strategy in an oral radiographic interpretation class, which motivated students and helped them to recognise misconceptions.[12] However, beyond the perceived interest value of the tool, it is important to see if CMs can effectively identify students' difficulties with structuring and understanding knowledge. Constructing a CM promotes exploration of the structure of one's knowledge and makes it accessible and visible. Consequently, we integrated CMs into a first-year dental course and attempted to evaluate the maps produced by students and, thus, answer our research question: *How do students structure their knowledge from a first-year dentistry course using a CM, and what is the relevance of the concepts in the CMs produced?*

2 | METHODS

2.1 | Sample

This study was conducted at the UCLouvain faculty of dentistry in Belgium during the second semester of the first year of a bachelor's programme in dentistry. A total of 43 students were registered for the course 'Elements of statistics applied to dental epidemiology and prevention', and they all participated in the study. They produced CMs for the four topics in this course. The CMs produced by some students were excluded from the analysis because the students failed to follow the instructions given during the first session, the CMs produced were not usable or they did not submit CMs for all topics. Therefore, our final sample is based on the analysis of the CMs produced by 31 students (20 F and 11 M; average age = 19.39 y ± 2.40). For each topic, students produced one CM. Thus, 124 CMs were examined in this study.

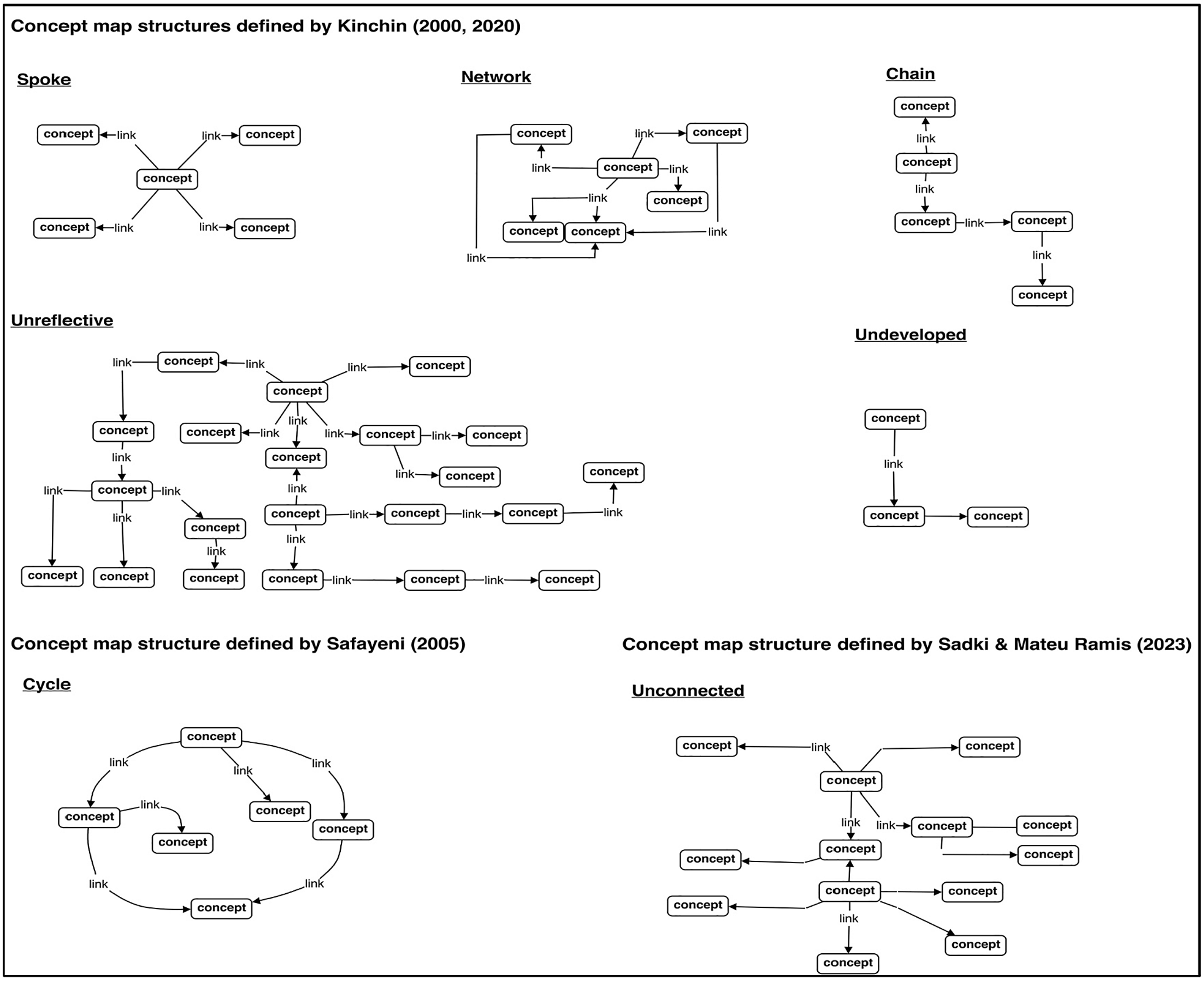


FIGURE 1 Concept map morphologies.

2.2 | Course content and concept map training

The content in this course is articulated around four topics. The first two are clinical, and the last two are essentially theoretical. Topic 1 explains the main indices for measuring oral health and how to use them. The second topic focuses on prevention and oral hygiene and explains the main oral and general environmental factors that can influence individual and collective oral health. The third topic, which describes the scientific approach, provides the student with all the elements needed for a scientific approach. At the end of this topic, students must apply and contextualise what they have learned to a clinical situation proposed by the teacher. Finally, the purpose of topic 4 is to give students some basics of common statistical methods. Students should be able to use basic statistical concepts in the critical reading of scientific dental literature, specifically about dental epidemiology and prevention, and be prepared to apply them in subsequent clinical decision-making.

Teachers have integrated regular CM seminars to promote active learning. At this stage of the students' training, the implementation of CM had two aims. First, to provide students with an original learning activity to let them learn differently. Second, to let them visualise the knowledge acquired and evaluate their level of comprehension.

At the beginning of the course, a training session was organised to explain what a CM is and to teach students how to use 'Cmaptools' software to draw their CMs. Then, students were asked to produce a CM around each topic at four different times during the course (see Figure 2). Within 3 days after the end of each topic, students were required to submit the CM for that topic on the course platform.

2.3 | Analysing CM through qualitative and descriptive approaches

All CMs were evaluated by two examiners: the course instructor and a dentist. First, they developed the methodology for analysing the CMs, then they analysed the CMs independently, and finally,

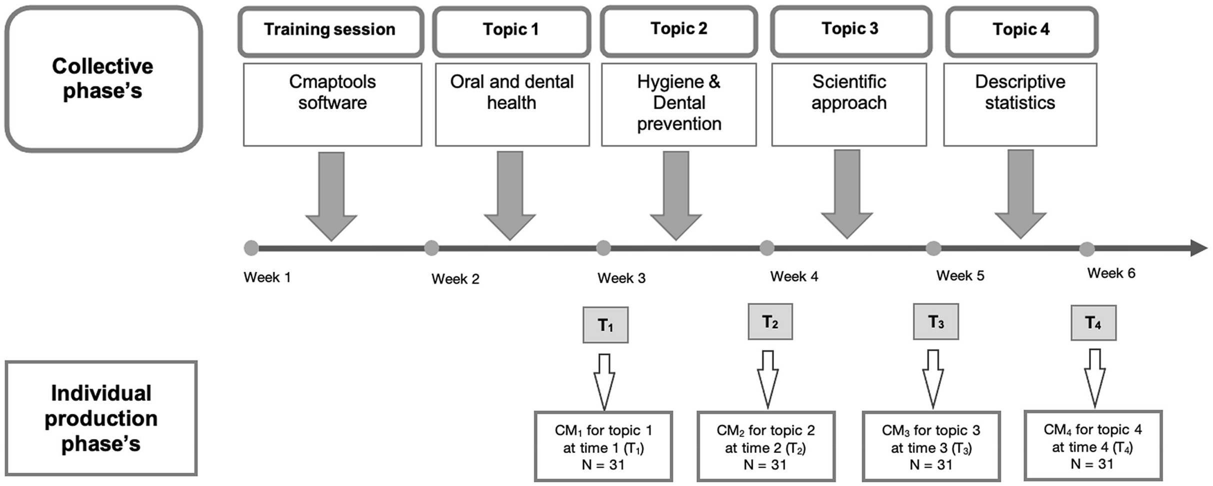


FIGURE 2 Research protocol.

they compared and validated their analysis collegially. The morphology of the CM was determined using descriptions found in the literature.[7,13,14] Examiners determined each map's morphology based on the map's overall look, the overall number of concepts, the geographic organisation of the propositions, and the presence or absence of links across the propositions (qualitative approach). In addition, the teacher pre-defined 20 key concepts for each topic (see Table 1). For each CM, the examiners counted the total number of concepts and the number of key concepts (descriptive approach).

Through sharing their independent results, the examiners were able to identify disagreements between their qualitative analyses and assess the degree of agreement between them. The examiners discussed any disagreements to reach a consensus. To evaluate the reliability of the identification of the morphologies, they carried out a test-retest comparison 6 months after the first analysis. Cohen's coefficients were 0.90 for the first topic, 0.95 for the second topic, 0.77 for the third topic and 0.91 for the last topic. All kappa tests were statistically significant ($p < .001$). Values exceeding 0.75 are considered to indicate excellent agreement.

All statistics reported in this study were calculated using SPSS (version 28) and the R language (version 4.2.2).

3 | RESULTS

A total of 31 students produced CMs for four different topics over time. Morphology and content (concepts and key concepts) were the two indicators used in the analysis of the structure and quality of the CMs. Table 2 shows the results obtained (More details can be found in the Supporting Information).

3.1 | Morphology and content

Five of the morphologies described by Kinchin were observed in the CMs, but with different relative frequencies. Representative examples of CM morphology, drawn by students, are shown in Figures 3–8 (The six maps, originally produced in French, have been translated into English). The students represented the concepts differently for the different topics. A new morphology appeared in our sample, which was almost similar to a mind map but was distinguished by the presence of some links. We labelled it an 'unconnected' structure and illustrated it in Figure 1.

In addition to morphology, the content of the CMs in terms of concepts varied for each topic. The average total number of concepts (TNC) increased over time and ranged from 51.29 to 66.26 concepts. The average RKC varied from topic to topic. The results per topic follow.

3.1.1 | Topic 1: Oral and dental health

About one-third (35.5%) of the 31 maps produced for this topic had a spoke morphology. The other morphologies were present with different relative frequencies, but there were more undeveloped and unconnected maps than the others. The network and cyclic structures were seen the least often. The undeveloped structure contained the lowest number of concepts. The unconnected and the spoke structures generally had the same TNC. The unreflective structure stood out with a very high TNC. The RKC varied according to morphology and was weaker on maps with an undeveloped structure.

3.1.2 | Topic 2: Hygiene and dental prevention

The undeveloped structure was the most frequent (32.3%) for this topic. The other morphologies were all present, but with variable relative frequencies. The unreflective structure was distinguished by a greater TNC, on average. The mean TNC for the other morphologies remained lower. The average RKC in the 31 CMs representing this topic was highest in the unreflective and network structures.

TABLE 1 Key concepts defined by the teacher for each topic – translated into English.

TOPIC 1 Oral and dental health	TOPIC 2 Dental hygiene and prevention	Topic 3 Scientific approach	TOPIC 4 Descriptive statistics
1. Epidemiology	1. Dental caries	1. Evidence-based dentistry (EBD)	1. Data (or data collection or database)
2. Prevalence	2. Substrate factor	2. Empirical observations – explicit reasoning	2. Distribution
3. Incidence	3. Frequency of ingestion (or pattern)	3. Refutability (objective vs. subjective approach)	3. Frequency
4. Dental caries	4. Sugar substitute (xylitol, sorbitol ...)	4. Theoretical framework	4. Qualitative variables
5. Caries Index	5. Carbohydrate (sugar)	5. Reliability of the measure	5. Quantitative variables
6. DMFT-DMFS; Permanent tooth	6. Microbial factor	6. Validity of the measure	6. Central tendency (mean; median; mode)
7. dmft-dmfs Temporary tooth	7. Bacteria	7. Stages of research (or structure of a scientific article)	7. Symmetry (left/right asymmetry) or bell-shaped distribution (Gaussian curve)
8. Surface (unit of measurement)	8. Dental plaque	8. Research design	8. Dispersion (range; standard deviation; variance)
9. Tooth (unit of measurement)	9. Carious process	9. Type of study: observational vs. experimental (one of the 3 concepts)	9. *Z*-score (relative positioning)
10. Diagnostic levels or image with the 6 levels of tissue loss	10. Cariogenic biofilm/periodonto-pathogenic biofilm	10. Sample or random sample	10. Box plot
11. Clinical examination	11. Terrain factor	11. Bias	11. Correlation
12. Radiographic examination	12. Drop in pH	12. Randomisation	12. Regression
13. Classification by location	13. Buffer power of saliva	13. Controlled variables	13. Pearson's coefficient
14. Periodontal disease	14. Demineralisation	14. Confounding factors	14. Significance threshold
15. Periodontal probing	15. Remineralisation	15. Double-blind validation	15. Linear relationship
16. Periodontal pocket (depth)	16. Over-saturation	16. Dependent variables	16. Independent variable (explanatory; predictive)
17. Dental plaque	17. Under-saturation	17. Independent variables	17. Dependent variables (response)
18. Plaque index	18. Critical pH	18. Quantitative data	18. Regression equation
19. DPSI	19. Hydroxyapatite	19. Qualitative data	19. *p* Value
20. Indicators (bleeding, calculus and pocket)	20. Saliva and composition	20. Statistics	20. Inferential statistics

3.1.3 | Topic 3: Scientific approach

As shown in Table 2, 48.4% of the 31 CMs for this topic were organised in a spoke structure. No cyclic structure was found. Unconnected structures made up 22.5% of the students' CMs. The unreflective structure had the greatest TNC. The average RKC differed across the different morphologies and remained weaker in undeveloped structure.

3.1.4 | Topic 4: Descriptive statistics

Except for the cycle structure, all morphologies were present, with different relative frequencies and varying TNC. The unreflective structure again had the highest TNC, as in the previous topics. As shown in Table 2, on average, we found 66.26 concepts per CM, but the average number of key concepts did not exceed 10.58, which weakened the RKC (0.53). The undeveloped structure had the lowest RKC, compared to the other morphologies.

The analysis of morphologies and content within each topic, as well as comparisons of the TNC and RKC, showed that there is indeed a difference between students' CMs within a topic.

3.2 | Morphological and content evolution of CMs

As shown in Figure 2, to track the development of the morphology of the students' CMs, they produced four CMs (representing topics in the course) at four successive points in time. The morphology and CM content from T_1 (topic 1 at time 1) to T_4 (topic 4 at time 4) were quite variable (Figure 9).

TABLE 2 Descriptive statistics for CM characteristics for the four topics ($N_{total} = 124$).

	Topic 1 ($n = 31$) Oral and dental health		Topic 2 ($n = 31$) Hygiene and dental prevention		Topic 3 ($n = 31$) Scientific approach		Topic 4 ($n = 31$) Descriptive statistics		Relative frequency of morphology for all topics ($N_{total} = 124$)
	Relative frequency	Mean (SD)	Relative frequency	Mean (SD)	Relative Frequency	Mean (SD)	Relative Frequency	Mean (SD)	
a. CM by Morphology									
Undeveloped (UD)									
Total number of concepts	19.40%	25.50 (9.38)	32.30%	29.90 (10.14)	9.70%	34.00 (7.00)	9.70%	35.67 (2.52)	17.74%
Number of key concepts		9.17 (4.71)		10.30 (1.42)		10.67 (3.21)		8.00 (1.73)	
Ratio of key concepts		0.46 (0.24)		0.52 (0.07)		0.53 (0.16)		0.40 (0.09)	
Unconnected (UC)									
Total number of concepts	29.00%	50.22 (8.63)	9.70%	44.67 (2.51)	22.50%	55.71 (18.44)	22.60%	59.00 (12.84)	20.97%
Number of key concepts		11.67 (3.12)		13.33 (1.53)		14.1 (2.20)		9.71 (1.70)	
Ratio of key concepts		0.58 (0.16)		0.66 (0.08)		0.71 (0.11)		0.48 (0.08)	
Cycle (CY)									
Total number of concepts	3.20%	49.00 (–)	9.70%	40.20 (13.39)	0.00%	–	0.00%	–	4.83%
Number of key concepts		12.00 (–)		12.60 (2.89)		–		–	
Ratio of key concepts		0.60 (–)		0.63 (1.44)		–		–	
Unreflective (UR)									
Total number of concepts	9.70%	82.00 (7.00)	19.40%	97.50 (45.92)	12.90%	111.25 (33.83)	25.80%	90.13 (28.15)	16.94%
Number of key concepts		16.00 (0.00)		15.50 (2.51)		18.25 (0.96)		12.38 (1.92)	
Ratio of key concepts		0.80 (0.00)		0.78 (0.12)		0.91 (0.05)		0.62 (0.10)	
Spoke (SP)									
Total number of concepts	35.50%	55.55 (16.57)	9.70%	47.00 (12.53)	48.40%	58.20 (13.67)	29.00%	59.44 (12.32)	30.65%
Number of key concepts		14.18 (2.68)		12.33 (1.53)		16.00 (2.65)		9.44 (1.88)	
Ratio of key concepts		0.71 (0.13)		0.62 (0.77)		0.80 (0.13)		0.47 (0.09)	
Network (NW)									
Total number of concepts	3.20%	79.00 (–)	12.90%	61.25 (5.62)	6.50%	70.50 (2.21)	12.90%	69.50 (9.75)	8.87%
Number of key concepts		20.00 (–)		15.25 (2.75)		16.50 (0.71)		13.00 (2.00)	
Ratio of key concepts		1.00 (–)		0.76 (0.14)		0.82 (0.03)		0.65 (0.10)	
b. All CM									
Total number of concepts		51.29 (19.73)		51.77 (32.24)		62.94 (26.36)		66.26 (23.27)	100%
Number of key concepts		12.77 (3.89)		12.81 (2.87)		15.39 (3.00)		10.58 (2.42)	
Ratio of key concepts		0.64 (0.19)		0.64 (0.14)		0.77 (0.15)		0.53 (0.12)	

Ratio of key concepts $= \frac{\text{Number of key concepts}}{\text{Number of key concepts expected (20)}}$.

Abbreviations: CM, concept map; *n*, number of concept maps for each topic; SD, Standard deviation.

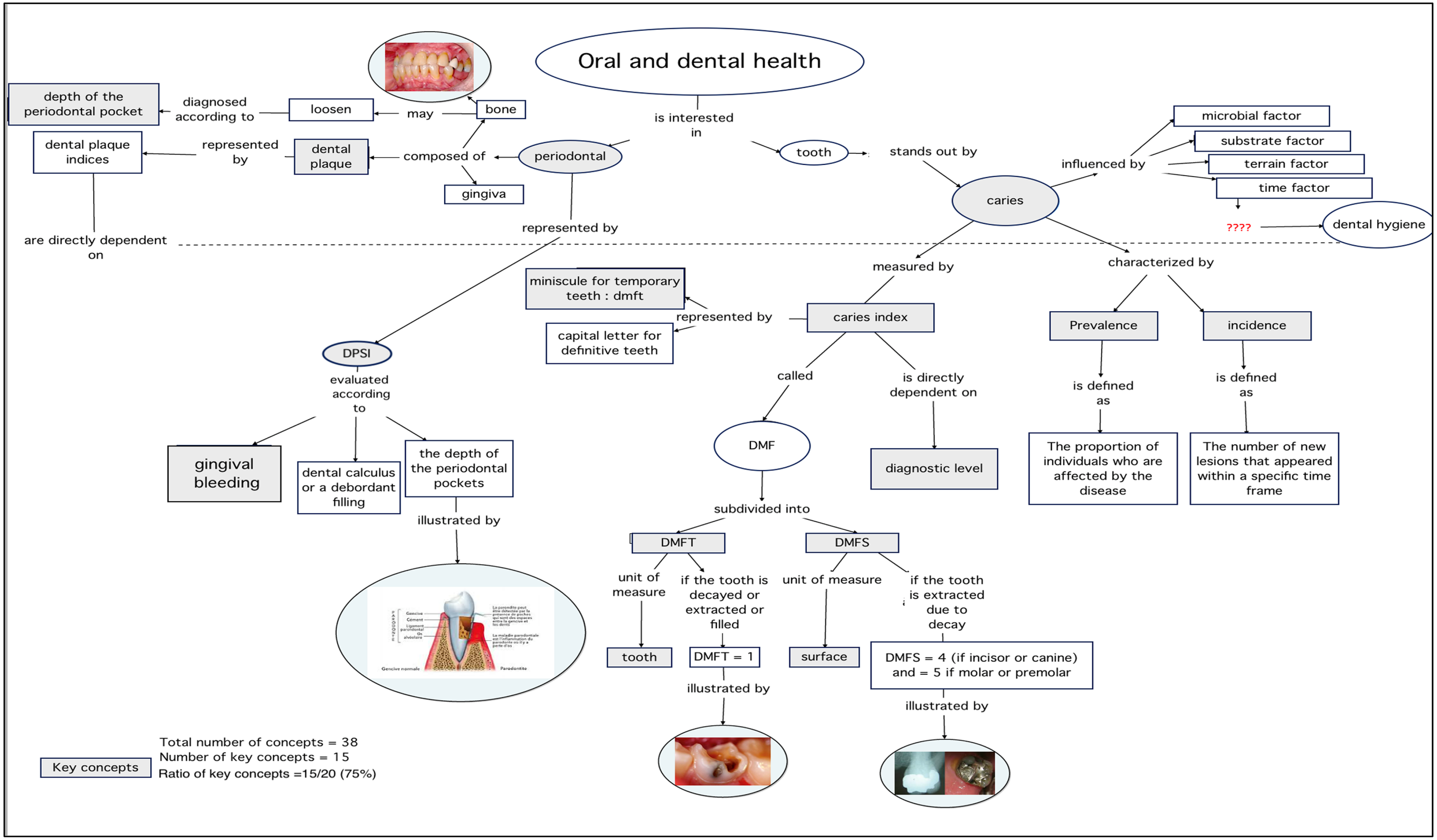


FIGURE 3 The representative concept map of the first topic 'oral and dental health' with a spoke structure.

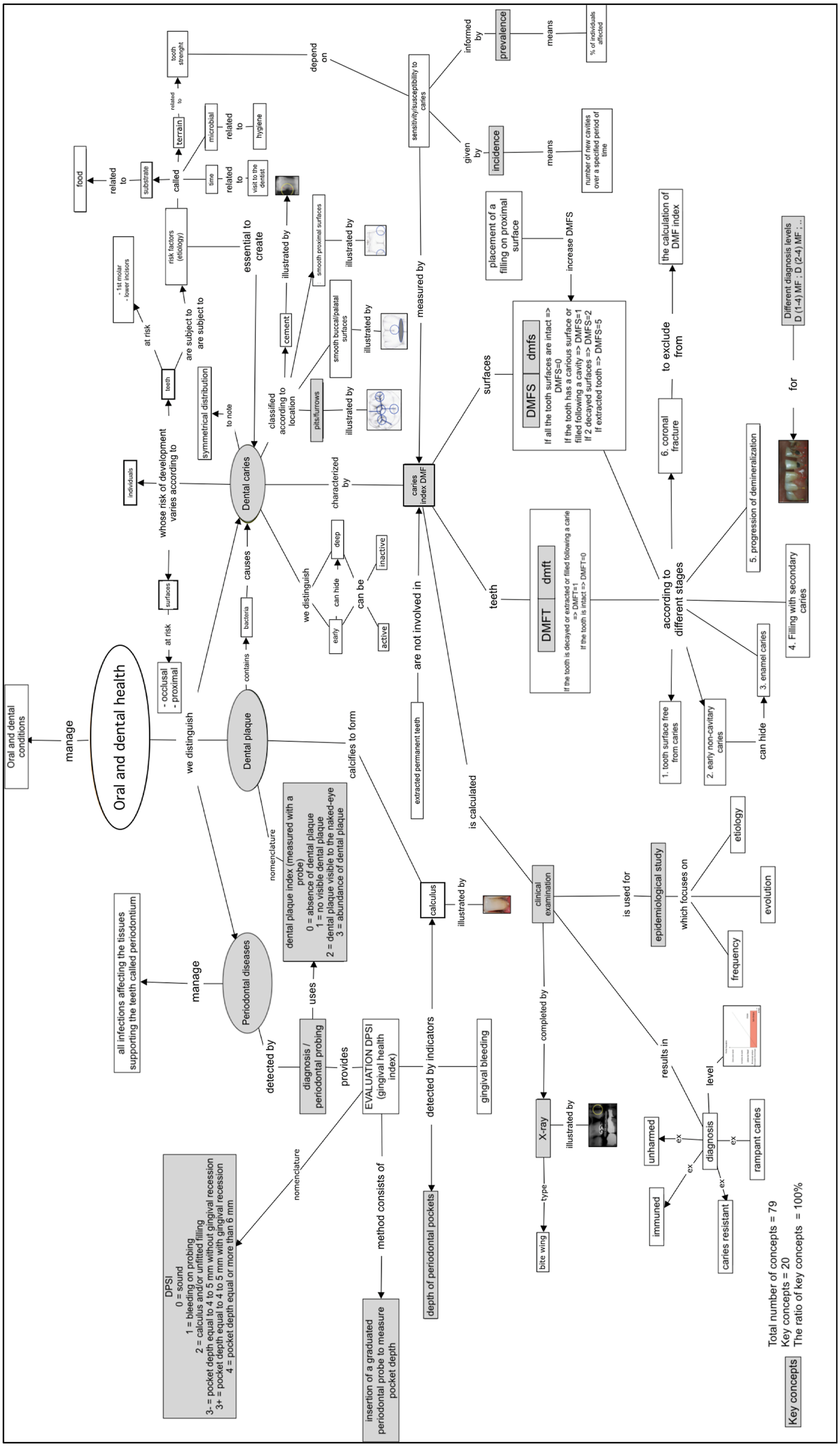


FIGURE 4 The representative concept map of the first topic 'oral and dental health' with a network structure.

Only a few students remained constant in how they presented knowledge. They maintained the undeveloped or unconnected morphology from topic 1 to topic 4. Only one student produced a network-structure CM for topic 1, but did not sustain it. Students who produced spoke structures for topic 1 either progressed to producing CM networks or used the other morphologies, except for undeveloped. No student using an unreflective structure for topic 1 switched to a network or undeveloped structure. The students who produced cycle structures for topic 1 or topic 2 followed up by using undeveloped, spoke or unconnected structures. We also found that the unconnected structure showed more variability in its evolution. It evolved into other types of morphology except for the network structure. Finally, the undeveloped structure was replaced by other structures, except for a network or unreflective structure.

With regard to the richness of the content of all CM, the TNC was, on average, identical for the first two topics. This number increased for the following topics: the students identified more concepts. The same was true for the RKC from topics 1 to 3, but this ratio decreased drastically for the last topic at time 4 (Table 2).

4 | DISCUSSION

The quality of CMs can be determined by several indicators (morphology and concepts), and reflects the quality of students' learning.[15] Making CMs requires time to assimilate and appropriate the knowledge, but can be impacted by the nature of the subject matter. In this study, we found that students structured their knowledge differently for the same topic. We noted that the evolution of the morphology and content in their CMs could depend on a combined effect of topic and familiarity with the use of CM.

Four different topics were represented using the CMs. The students' CMs included the morphologies described by Kinchin.[15] An interesting point was the additional emergence of unconnected morphology, which was not mentioned in the literature.

For the same topic, students used morphologies representing cognitive structures with sometimes poor connections or, conversely, structures that represented better understanding of the content. This diversity could be explained by each student's capacity to externalise the acquired concepts and to represent them graphically. Difficulty with mastering content could be seen in a student's CM. According to Jarvis, when the organisation of knowledge does not evolve, this is considered non-learning.[16] When the structure becomes elaborated, the learner's understanding improves, and knowledge can be structured into distinct morphologies.[17,18] As a result, different students do not structure the same topic-related concepts in the same way.

The network CM structure was poorly represented in our results. The crosslinks found in some maps indicated that some students could contextualise concepts from other courses, such as dental anatomy. This type of knowledge structuring expresses a high level of understanding and more meaningful learning. It includes the highest level of RKC and a multitude of relevant cross-links. We expect that because the students were at the beginning of their training, they were not advanced enough in their training path to be able to identify the relevant interconnections. It would be interesting to exploit the potential of CMs to investigate students' cognitive structures at a more advanced stage of training.

Some of the students' products had a spoke structure. Overall, this was the most abundant morphology. The arrangement of concepts through branching from one or more central units is often described in the literature as surface learning; concepts appear as

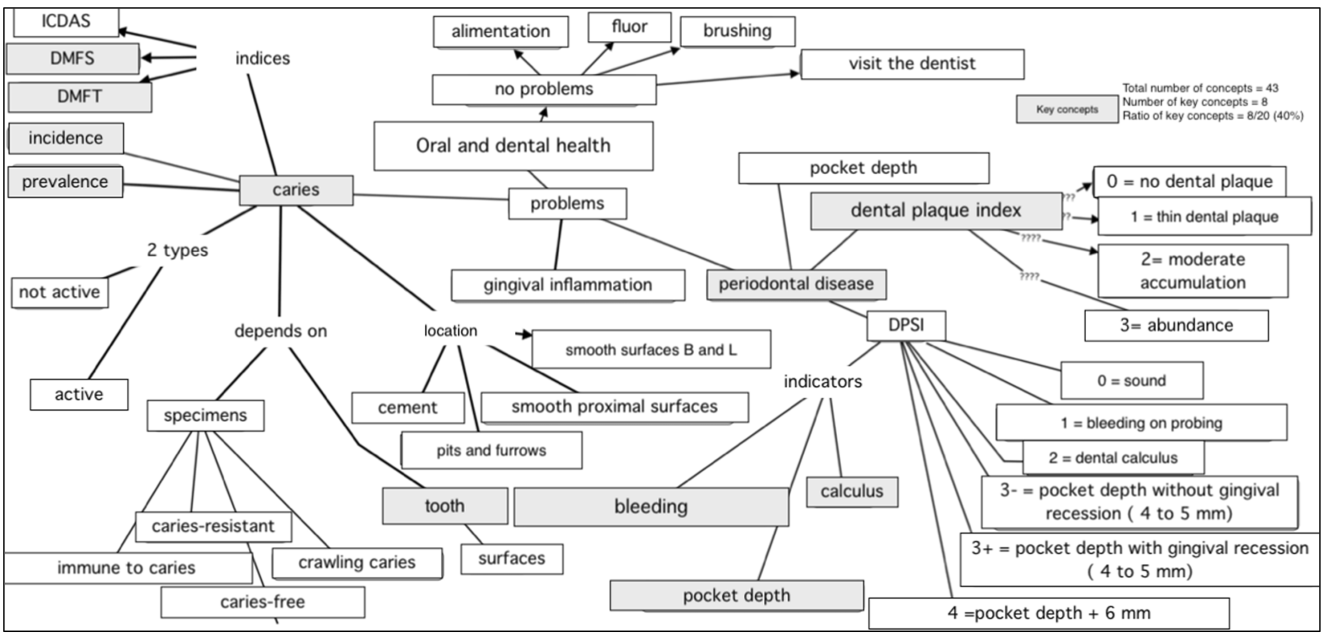


FIGURE 5 The representative concept map of the first topic 'oral and dental health' with an unconnected structure.

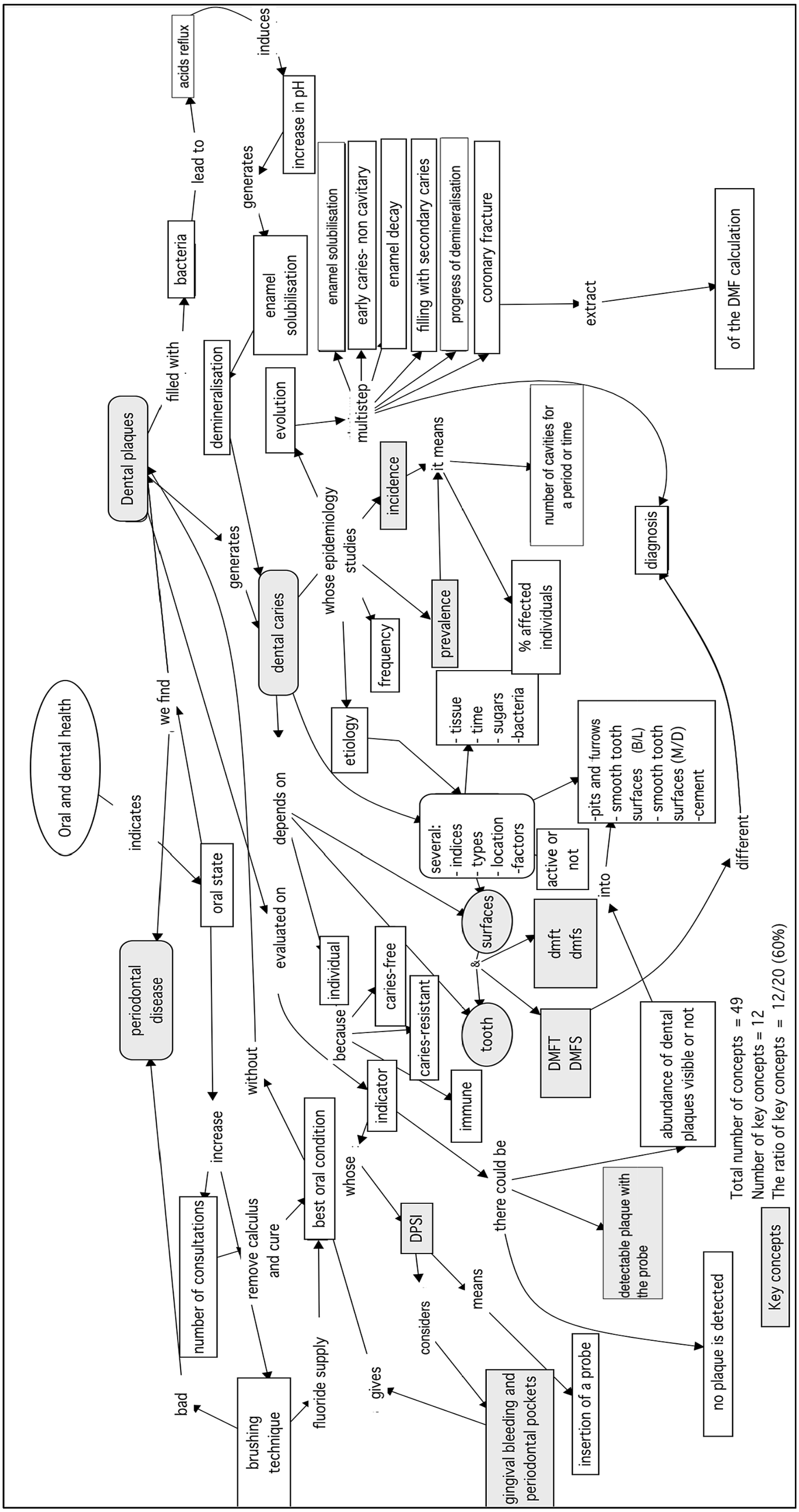


FIGURE 6 The representative concept map of the first topic 'oral and dental health' with a cyclic structure.

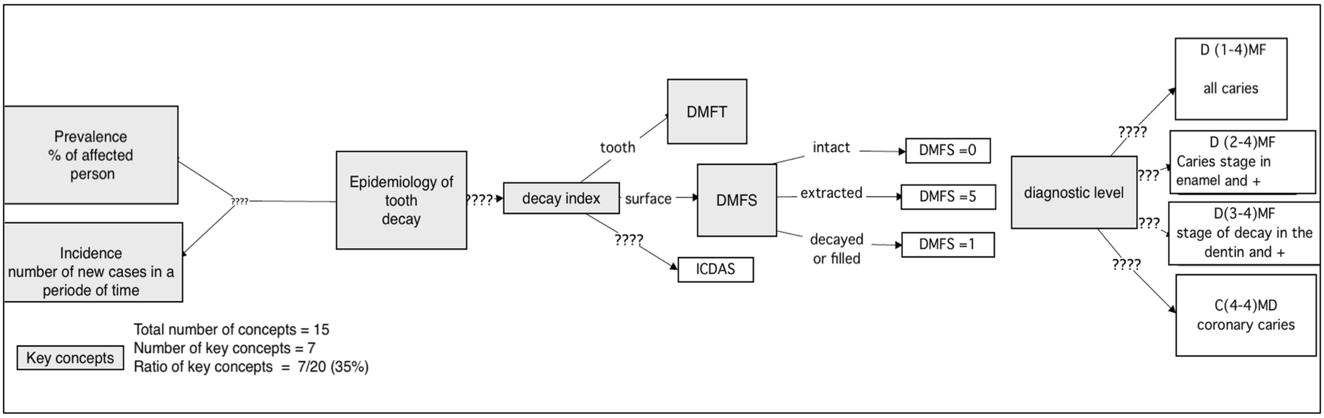


FIGURE 7 The representative concept map of the first topic 'oral and dental health' with an undeveloped structure.

fixed units that are not interconnected.[19] The spoke morphology also highlighted that many students were able to put concepts together by incorporating key concepts, but faced difficulties in establishing connections between concepts that were graphically distant. Although CMs support reflection during the learning process, spoke structure limits this advantage and does not present connections that reveal deep understanding. Nevertheless, it indicates that the student is a novice capable of learning, whose cognitive structure can evolve into a network structure.[11]

In an unreflective structure, the number of concepts is very large (more than 80 on average), but the student who produces an unreflective CM cannot distinguish important knowledge from details. Their CM is very cluttered, with a structure that becomes complex and difficult to understand. The unreflective structure is considered preliminary to developing a network structure.[7] However, this characteristic did not appear distinctively in our results.

The cycle structure facilitates the representation of functional relationships between concepts and encourages dynamic thinking.[14] However, it did not appear as such in our study. By connecting concepts and links using looping arrows, the students may have attempted to create cross-links to highlight the interconnections between concepts. We suggest that this discrepancy may be due to the nature of the topics represented, whose content does not necessarily present obvious dynamic connections for the student, as in course content such as biochemistry (Krebs cycle).[20] The student probably tried to develop a network structure without looking for the most relevant cross-links. The final product was blocks of maps organised in a loop, but unfortunately, the attempt to achieve a clearer representation was not achieved. This structure disappeared for the last two topics, probably due to clarification of how cross-links are represented in a CM.

We particularly noted the occurrence of the unconnected CM structure. It is characterised by the presence of general and key concepts in the same order as in spoke structure, indicating that the student has received the information, but is not able to make the connections between concepts, unlike spoke structure. The student goes beyond the stage of an undeveloped structure, but lacks the links to express a better understanding of the concepts acquired.

The undeveloped structure represented content-knowledge weakness. This may be related to a lack of knowledge or a lack of appropriate terms to form connections that will initiate the learning process.[7] This process, as triggered by making the CM, requires an understanding of the concepts needed to build a relevant CM.

The CMs allowed us to observe the differences in cognitive structuring for the same topic. This diversity of structuring allows students to discover how they structure information during their learning. Furthermore, through the CM, the teacher can identify the difficulties encountered and set up strategies to remedy them. The morphology of CMs, as well as the presence of key concepts, was an effective way to explore the diversity of the CMs students created. The presence of key concepts is necessary but not sufficient; the student also must make good-quality connections to form valid propositions that express the knowledge acquired.

A CM is a pedagogical tool that can highlight how the way we learn changes as we go along.[21] Many researchers have used them to track the development of cognitive structures over time.[22–24] Cañas's study showed that students are concerned first with mastering the tool and then the content, and that over time, as they become more comfortable with CMs, their maps become larger.[22] Over time, they generally put more effort into finding appropriate linking phrases, but they still do not spend much time thinking about the best linking phrase to construct a proposition. Therefore, intuitively, we expected to see better products as the students familiarised themselves with the tool, but the results obtained in this study do not show this progress. Although the total number of concepts in the maps increased over time, the morphology of the CMs evolved (or not) differently.

The network and spoke structures did not change into undeveloped structures: regardless of the topic, students may have scattered ideas while trying to put as much information as possible into a map, or they may remain stable in their graphical representations, which reflects deeper learning because they manage to find the concepts to link them.

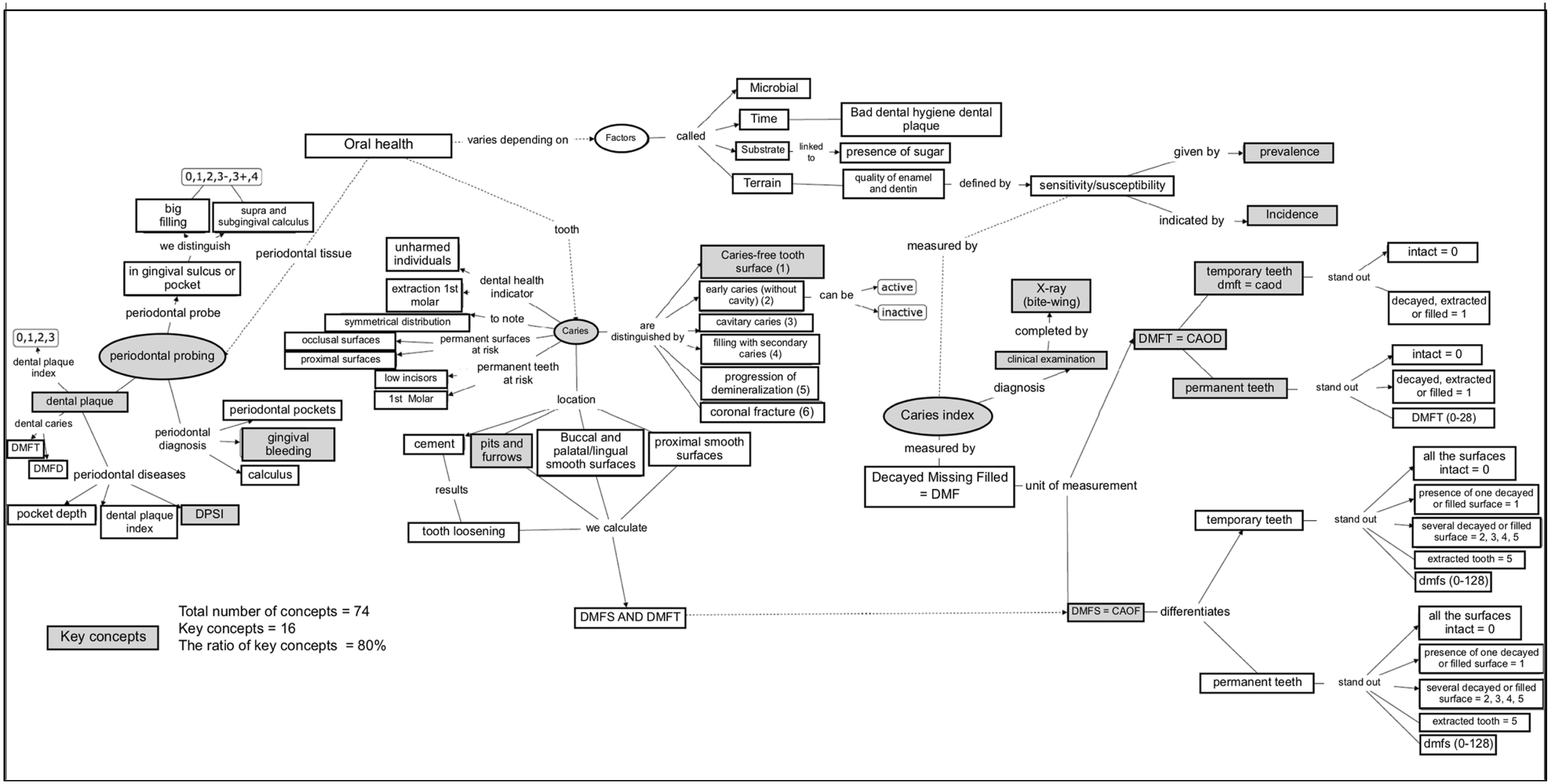
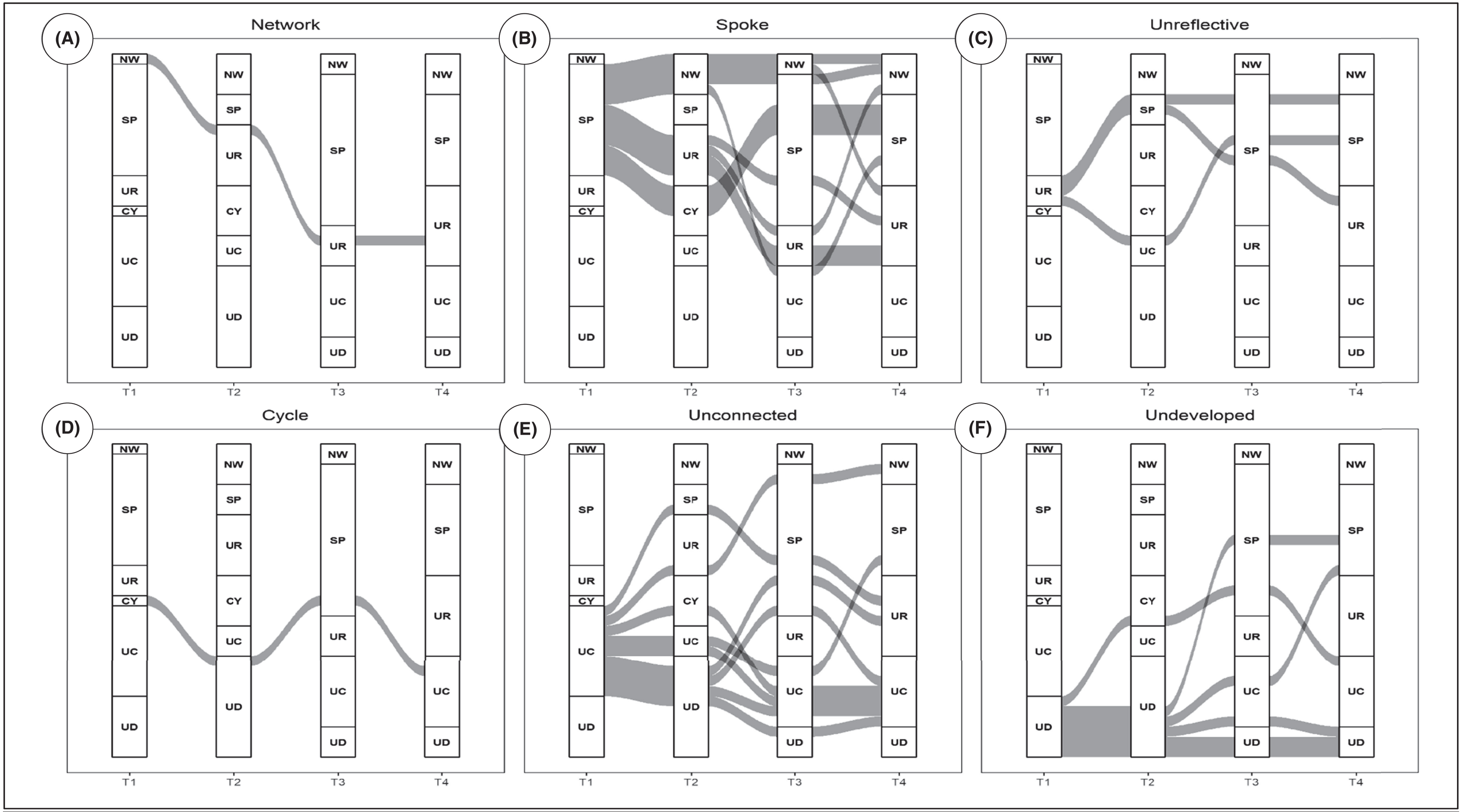


FIGURE 8 The representative concept map of the first topic 'oral and dental health' with an unreflective structure.



CM: concept map; NW: Network ; SP: Spoke ; UR: Unreflective; CY: Cycle ; UC: Unconnected; UD: Undeveloped ;

T_1 :time 1 and topic 1 ; T_2: time 2 and topic 2; T_3 : Time 3 and topic 3 ; T_4 : time 4 and topic 4

A: Evolution of the network structure from T_1 to T_4
D: Evolution of the cycle structure from T_1 to T_4
B: Evolution of the spoke structure from T_1 to T_4
E: Evolution of the unconnected structure from T_1 to T_4
C: Evolution of the unreflective structure from T_1 to T_4
F: Evolution of the undeveloped structure from T_1 to T_4

FIGURE 9 Evolution in the morphology of students' CMs from topic 1 to topic 4. CM, concept map; CY, Cycle; NW, Network; SP, Spoke; UC, Unconnected; UD, Undeveloped; UR, Unreflective; T_1: time 1 and topic 1; T_2: time 2 and topic 2; T_3: Time 3 and topic 3; T_4: time 4 and topic 4. (A) Evolution of the network structure from T_1 to T_4. (B) Evolution of the spoke structure from T_1 to T_4. (C) Evolution of the unreflective structure from T_1 to T_4. (D) Evolution of the cycle structure from T_1 to T_4. (E) Evolution of the unconnected structure from T_1 to T_4. (F) Evolution of the undeveloped structure from T_1 to T_4.

The unreflective structure indicates that the student knows how to make links and uses a lot of concepts but is not able to select the most relevant ones. If this student is guided to focus on the most useful concepts (avoiding overlapping concepts), one could expect improvement.

The unconnected structures could evolve to become network structures. At the beginning, the student does not manage to express links; once these links are acquired, there could be a shift towards better structures.

In contrast, students who produce undeveloped structures have difficulty developing concepts. Consequently, without particular supervision, no growth will be evident, because the lack of concepts represents a brake to learning.

In summary, this lack of development in students' CMs could be due to the students' lack of ability to progress. Difficulty with externalising knowledge could be related to the intrinsic characteristics of the student, as also mentioned in Ifenthaler's study.[24] The construction of a CM is a complex task for an unskilled learner, who will have difficulty positioning the concepts and linking them.[25] Kinchin suggested that a single map is insufficient and recommended observing the evolution of cognitive structures over multiple CMs.[15] Several studies found that some topics can be difficult for learners to map (e.g., cellular respiration in biology; carbon cycle).[26,27] Our results seem to indicate two coexisting factors: topic and level of familiarisation with the CM tool. Indeed, morphologies did evolve into both more elaborate structures and structures that reflected the difficulties of structuring. The content of the CM was affected by both of these factors, since the number of key concepts evolved at the beginning but decreased sharply for the last topic. Some concepts are more problematic than others. Thus, we noticed differences from one topic to another. Students were more engaged with topics 1 and 2 and had less difficulty identifying key concepts compared to topic 4, which focused on descriptive statistics.

As Jonassen pointed out, the identification of cognitive structures also benefits the teacher.[9] It helps the teacher organise the content of the course and adapt it according to the difficulties and gaps identified by the students' CMs. Once the teacher has identified the knowledge acquired (or not) by these students, feedback is another important part of the learning process. For the CM tool to be effective in enhancing students' learning and making their thinking visible, the teacher must provide feedback and the student must engage with it. Indeed, feedback improves the structural quality of concept maps.[28] Teacher feedback and timely mobilisation of information are key elements in the learning process.[29,30]

Therefore, a CM is an interesting tool for both the student and the teacher. The student can connect the concepts learned in many directions, and the CM can be continually updated to incorporate new information.[21] The teacher must be aware of the multiple starting points that a student may have when producing a CM.

This study has two important limitations. First, producing a map requires at least one training session. Not all of our students acquired the ability to use the Cmaptools software. Some of them expressed the difficulty of producing maps with Cmaptools, which became restrictive for them because they had to produce computerised maps. Second, we observed the coexistence of the topic effect and familiarisation with the tool, but our research protocol did not allow us to observe their effects separately.

The main difficulty we encountered in this study concerned the analysis of maps with an excessive number of concepts, which could require, from a more precise analytical perspective, restricting the number of concepts included in a CM.

5 | CONCLUSION

The literature promotes the use of CMs as an essential learning strategy. Concept mapping is commonly used in educational contexts to explore students' understanding of concepts and their cognitive structures. Through the presence, relevance and patterning of concepts in a CM, we can assess the quality of learning. To our knowledge, no study has addressed both structural (morphology) and content analyses of CMs, which we did in this article. We saw that different students structure their knowledge differently for the same topic. Some have more difficulty identifying key concepts. Moreover, the quality of the CM seems to be remarkably affected by the nature of the topic, even when the map is produced after learning has presumably occurred.

This study found that describing CM's morphologies and their content in terms of concepts provided interesting indicators. Nevertheless, future work should also explore the semantic quality of the propositions in CMs.[31] To optimise the use of CMs in the classroom, students must be able to identify key concepts and articulate them appropriately with relevant links. While developing proficiency with this tool requires time, the teacher must be mindful of the topic's impact, for which contextualisation is highly recommended.

Finally, CM use is particularly interesting in dental education, which involves different types of knowledge that the student must connect to progressively evolve from novice to expert status. Following this work, in-depth qualitative analysis of the CMs remained to be conducted and will be the subject of a future publication.

AUTHOR CONTRIBUTIONS

Asmaâ Sadki contributed to teaching in the course; AND to the conception and design of the work, the acquisition, analysis and interpretation of data for the work; AND drafting the work and revising it; AND final approval of the version to be published; AND agreement to be accountable for all aspects of the work. Séverine Mateu-Ramis contributed to the acquisition, analysis and interpretation of data for the work; AND contributed to drafting the work and revising it critically for important professional content; AND final approval of the version to be published; AND agreement to be

accountable for all aspects of the work. Gaëtane Leloup contributed to teaching in the course; AND to the conception and design of the work, AND final approval of the version to be published. Mariane Frenay contributed to the interpretation of data for the work; AND contributed to drafting the work and revising it critically for intellectual content; AND final approval of the version to be published.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Approved by the local Ethics Committee.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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