CHAPTER 2

VISUALISING KNOWLEDGE

Applying Concept Mapping

INTRODUCTION

Very often in my classes over the years students have come to me to announce that they are ‘stuck’ and ‘don’t understand’. A conversation then takes place in which I would ask things like, ‘where are you stuck?’ or ‘what don’t you understand?’. This then presents the student with an even greater problem – to explain what they do not understand. Unless they are able to pinpoint the problem (such as ‘I don’t understand the word, catalyst’, or ‘I missed the lecture on the origins of democracy’) it can be difficult for them to explain what they do not know, when they do not know it. As a teacher you then spend time trying to diagnose the source of the student’s problem. The obstacle then for the teacher is to try to ‘see’ what the difficulty is, particularly from the student’s perspective, which lacks the teacher’s disciplinary overview.

Then I discovered concept mapping (Novak & Gowin, 1984). This is a tool that helps me not only to see how the student is putting ideas together (or not), but can also help the students to diagnose their own difficulties. So now instead of students saying something vague like ‘I just don’t get it!’, they can come with more focussed questions such as ‘what is the connection between heat and evaporation?’. This is something concrete and defined where I can help the student without spending so much time finding out where the problem is. So at the very least, it guides students to ask better, more focussed questions.

Concept mapping was developed by Prof. Joe Novak at Cornell University in the 1970s, drawing on Ausubel’s Assimilation Theory of learning (see Ausubel (2000) for the most recent summary of this work). In a 12-year longitudinal study of conceptual change in high school students (Novak & Musonda, 1991), concept maps were used to represent students’ cognitive knowledge structures by organizing concepts into propositional networks. They used this to summarise data from taped interviews in a way that allowed the researchers to observe in detail the quality of conceptual change over several years. The concept mapping tool has continued to develop (Novak & Cañas, 2006; 2007) and the application of concept mapping has subsequently been explored in a large number of studies across a range of disciplines and educational levels (e.g. Nesbit & Adesope, 2006).

So if this is now all so simple, why isn’t everyone accessing student knowledge structures as a matter of course within their teaching? The difficulty many teachers have with adopting concept mapping seems to stem from years of rote-mode learning practice in their school setting (Novak & Cañas, 2007). If rote learning is the model that is followed within a classroom, then the students' prior knowledge and their developing knowledge structure are irrelevant (Figure 5). Teachers who are firmly rooted in the epistemological world view that there is a single correct answer to be acquired, memorised and reproduced will have difficulty in seeing the possible benefit of accessing students' knowledge structures through concept mapping. Some of these teachers will try concept mapping as a tool, but will often provide students with complete maps to memorize or with fill-in-the-gap mapping blanks to be completed by rote. Neither of these classroom scenarios will provide much in the way of enhancement to the quality of learning. A mechanistic approach to concept mapping will not generate the anticipated learning gains or support development of the expert student. One of the key factors that may indicate 'success' of concept mapping interventions is the enhancement of metacognitive skills (Salmon & Kelly, 2015).

The constructivist epistemology has been summarised by Novak (1993) as being based on the belief that from birth to senescence or death, individuals continually construct and reconstruct the meaning of events and objects they observe. This was developed into the human constructivist view as an attempt to integrate the psychology of human learning and the epistemology of knowledge production, which can be outlined in three key assertions: human beings are meaning-makers, the goal of education is the construction of shared meaning, and shared meanings may be facilitated by the active intervention of well-prepared teachers. Where teachers may not have had experiences within their own education that foster such a view of learning, they will need support to appreciate teaching models that stem from an epistemological standpoint that does not fit their own personal construction of learning (Cannella & Reiff, 1994). This may generate a lack of epistemological resonance between the curriculum and the concept mapping tool, and is a major barrier to the effective adoption of concept mapping as a classroom tool (Kinchin, 2001).

Figure 5 shows how epistemology is central to the application of Ausubel's Assimilation Theory of Learning (Ausubel, 2000) and the use of knowledge structures to reveal meaningful learning. In brief, on order to align the epistemology of the classroom to the human constructivist epistemology underpinning the evolution of concept mapping, it is helpful if teachers can start to envisage students as producers of knowledge (and eventually as transformers of knowledge) rather than passive consumers of information (Gamache, 2002). This constitutes part of the development of the well-prepared teacher that runs in parallel to the expert subject knowledge that teachers require.

CONSTRUCTING MAPS

There is a considerable and diverse literature on the nature of concepts, but in order to maintain consistency with the literature of concept mapping, and to provide a simple and practical way forward, I will simply follow the definition provided by Novak and Cañas (2007: 33) that a concept is '*a perceived regularity (or pattern)*

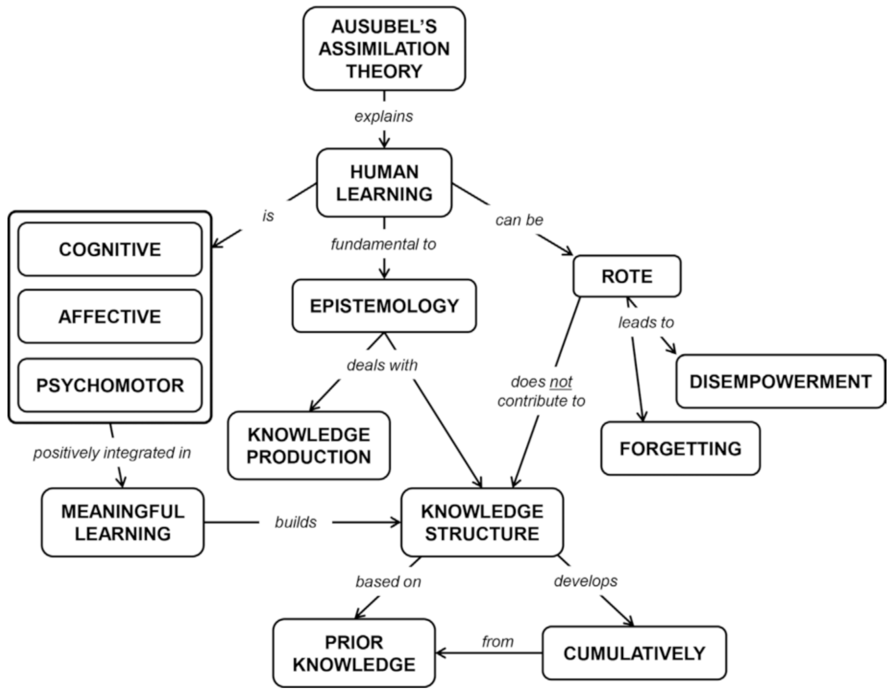

Figure 5. Relating epistemology to the development of knowledge structures (Developed from Novak, 2010)

in events or objects, or records of events or objects, designated by a label'. This provides sufficient flexibility and scope for colleagues to be able to apply this idea to their own disciplinary areas without difficulty.

In order to construct a concept map, the mapper first needs to consider the focus question that the map will address – the top concept (or root concept) to guide the construction of the rest of the map. Cañas, Novak and Reiska (2012) comment that teachers rarely spend sufficient time preparing the focus questions that are presented to students. So a map of 'British politics' will produce a particular type of map, whereas a map of 'the causes of change in British politics' will produce something a little different – and possibly more interesting.

Once the focus question is clarified, the mapper needs to consider which concepts should be included in the map. This requires a brief brain-storming session in order to create what many colleagues term 'a parking lot of concepts', from which the mapper can then select the most important for inclusion. There is usually no need to spend vast amounts of time on this process. Important concepts are usually those that spring to mind most quickly. Once concept labels are being arranged on the page, any gaps or omissions in the list of concepts will become apparent to the mapper. If not the gaps will be apparent to the teacher who will be evaluating the map, who may recognise this as a gap in the mapper's knowledge.

Once the mapper has the list of concepts to choose from they must then be arranged on the page,[1] each one written within a box,[2] in order start to create the structure of the map. Here the mapper has to choose which of the concepts are most important (these should go near the top of the map), and show the way in which items may be clustered to show the degree of relatedness. Arrows will then be drawn between the concepts to show the links that are intended. At this point, many novice mappers will think that they are almost complete. However, experience has shown that the most challenging part of map construction still remains – to formulate the linking phrases that populate the linking arrows to create propositions (concept → explanatory link → concept). These are the words that really convey the quality of meaning represented by the map. A map that lacks linking phrases conveys little or no meaning. The 'proto-map' in Figure 6 lacks any linking phrases and so the meaning of the map is ambiguous and the understanding held by the mapper is unclear. Some mappers will try to explain that 'the meaning is self-evident and does not need to be included'. This is often a claim made by senior students or even teachers who feel under pressure to reveal their thoughts and may be anxious that their ideas will be different to those held by the rest of the group. However, it is the potential variation in interpretation among the group that may foster meaningful dialogue and uncover previously hidden perceptions.

The more basic the idea, the more anxiety and reluctance to commit may be evident. For example, among a group of university lecturers, the link within the proposition STUDENTS→LECTURES will reveal considerable variation in view. Some colleagues will suggest that the arrow stands for 'must attend' whilst others might suggest, 'rarely attend'. Some colleagues will suggest 'learn in', whilst others will suggest 'are bored in'. The anxiety among mappers arises as their suggested link starts to reveal who they are and what type of lecturer they are. This level of anxiety is not so acute when students are concerned as they will consider that they are there to learn rather than to demonstrate their expertise.

The proto-map in Figure 6 is ambiguous in its current form and fails to demonstrate understanding of the topic.

The chain of propositions in Figure 6 that forms:

FOOD → BACTERIA → ACID

may elicit a variety of responses from students that reveals differing levels of understanding and misconceptions. For example, the responses below have both been offered by students of dentistry:

FOOD → provides nutrition for → BACTERIA → to create → ACID

FOOD → contains → BACTERIA → that release → ACID

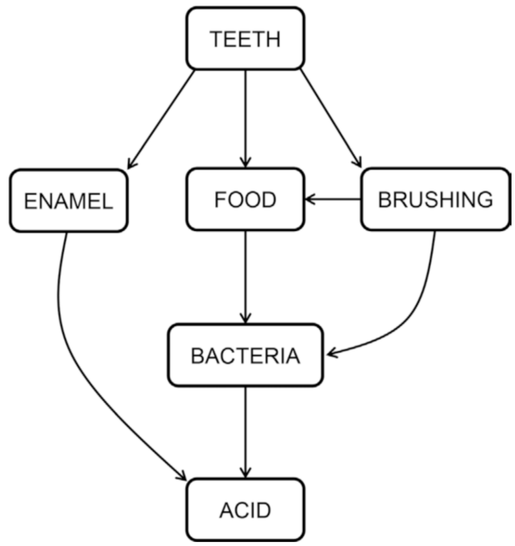

Figure 6. A ‘proto-map’ in which there are no labels linking the concepts

We can see here that the source of the bacteria and the source of the acid are not agreed upon by these students. The variety of understanding across the class would be hidden from the teacher’s view if s/he simply said to the group ‘we all know about the importance of acid on teeth and the role played by oral bacteria, don’t we?’. To which a typical round of communal nodding would suggest a single, unified understanding where none may exist. The linking phrases are, therefore, crucial to convey meaning.

CONSTRUCTING LINKS

We have seen that a lack of links fails to communicate understanding. The links and the labels placed upon them are the key factor that increases the expressive power of concept maps in comparison with other diagrammatic tools that may be employed in the classroom (Crandall, Klein, & Hoffman, 2006). The choice of linking words and phrases is therefore vital to convey the quality of understanding. Whilst a link may be correct, it may not be the ‘best’ or most instructive link. The mapper needs to think, how do the links help to move the map beyond the descriptive and towards the explanatory?

Dynamic relationships have been defined by Safayeni, Derbentseva and Cañas (2005) as those which establish implication, functional interdependence and covariation among the concepts. They are recognised within a concept map as those which imply movement, action or change. Miller and Cañas (2008) have developed this to consider dynamic propositions as either causative or non-causative. In the case of causative propositions, a relationship of cause and effect is evident. Examples of static, non-causative dynamic and causative dynamic relationships could be:

Static propositions:	The sky is blue. Practical theology includes homiletics.
Non-causative dynamic propositions:	Cars cost money. Children eat sweets.
Causative dynamic propositions (CDPs):	Economic stability attracts investment. Heat melts ice.
Quantified & qualified CDPs:	Aerated soil has a more diverse flora. Highly integrated maps suggest better understanding.

The two map fragments in Figures 7 and 8 are of about equal size and complexity, with neither offering a complete picture of the concept of animal cells. But even within these small fragments, differences in quality can be observed. The map at the top (Figure 7) lists structures found within cells and the map has very limited explanatory power. The map author is simply recalling what a cell contains. From what is presented we are unable to tell if the map author understands what the cell organelles do or indeed if there is any understanding of how these structures relate to each other. The limited understanding represented within this map is emphasised by the lack of variety used in the linking words.

In contrast, the map fragment in Figure 8 is much more dynamic. This stems in part from the author's choice of considering processes rather than structures, offering greater scope for developing linking phrases that offer greater explanatory power in the way the concepts are related, introducing ideas such as division, cleavage and movement.

As a consequence of these differences, the subsequent questions that these maps invite are also different. The teacher wishing to interrogate the understanding of the author of Figure 7 would probably have to start with questions that test factual recall: 'what is a mitochondrion?', 'what is cytoplasm?'. The map in Figure 8 invites more challenging questions: 'how do the chromosomes move?', 'what is the significance of the diploid number?'. Students need to be directed to think about the ways in which the concepts are linked and to try to go beyond the simple descriptive links to those that offer dynamism and explanation. The map is, therefore, not the end-product of learning (Wexler, 2001), but a step in the dialogue. The map needs to invite further steps to be taken and further dialogue in order to interrogate meaning.

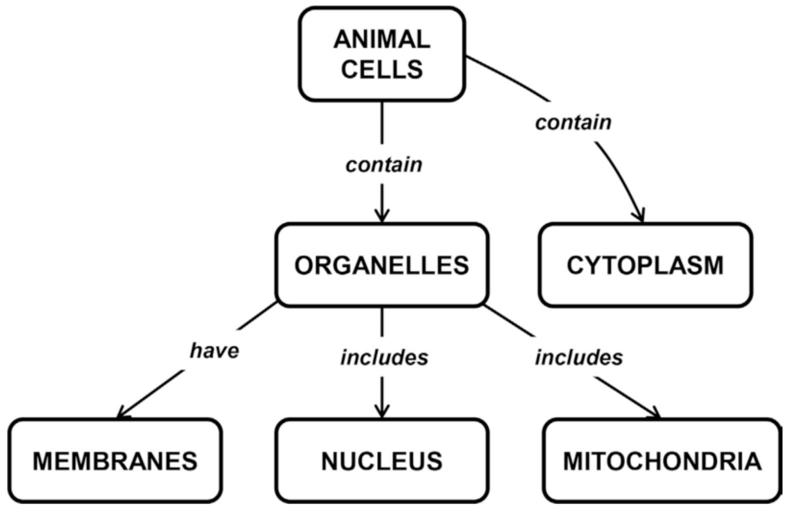

Figure 7. Student map of "Animal Cells" demonstrating passive links

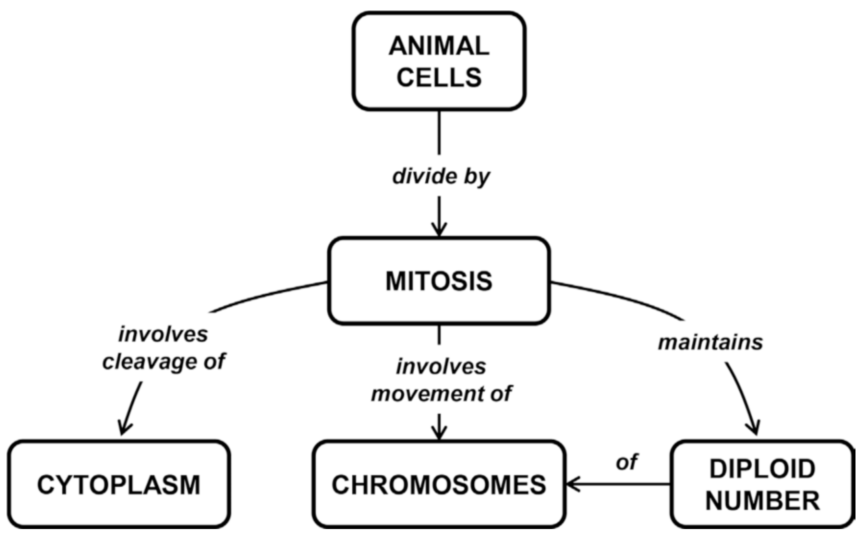

Figure 8. Student map of "Animal Cells" demonstrating active links

EXPLANATORY POWER

One of the most important questions to ask while generating a concept map concerns its explanatory power. This arises from the mixture of concept labels selected, linking phrases used and the overall morphology of the map, and is best explored through the analysis of an example. In Figure 9, the map of 'practical theology' does not seem to answer a question, except perhaps, 'what are the elements of practical theology?'. But even to this question, the map provides no explanation. The radial structure gives no hint of the ways in which the subordinate concepts might be linked, and the repetition of a single linking word (includes), indicates that this map is little more than a pictorial list of related concepts. Whilst it could be argued that there is merit in producing this map as an interim stage in the development of the student's understanding so that additional links and concepts could be added later, there is also the problem that some students (and teachers) may regard this a the finished item. The map's lack of explanatory power may then be seen as a weakness of concept mapping *per se*. This map structure is typical of those that are produced as the result of a brainstorming session (e.g. Moreira, 2012).

The map in Figure 10 is starting to develop some explanatory power to enrich ideas that are held under the umbrella term, 'practical theology'. The links are showing a degree of variation and use terms that offer insight to the quality of linkage. The two halves of the map are also integrated with a cross-link between 'theory' and 'practices'. The enhanced quality of this map over the map in Figure 9 is often generated as a result of dialogue with peers and/or personal reflection on the concepts. The development therefore takes effort and time.

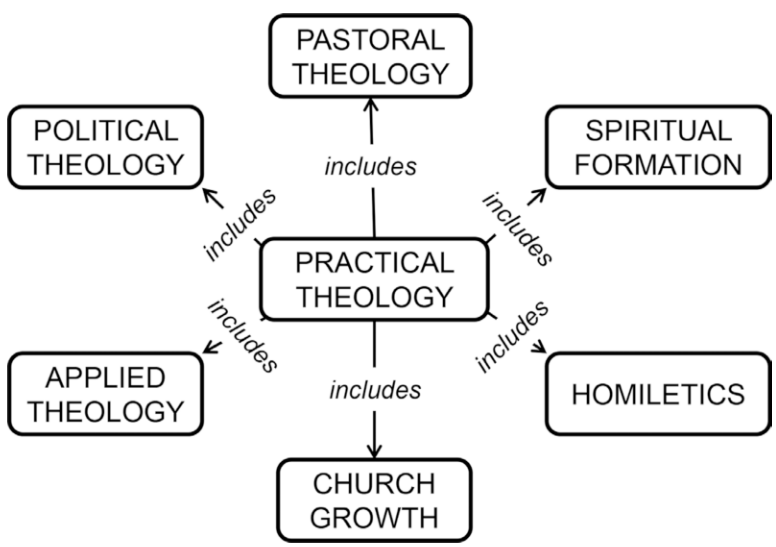

Figure 9. A student concept map of 'practical theology' demonstrating low explanatory power

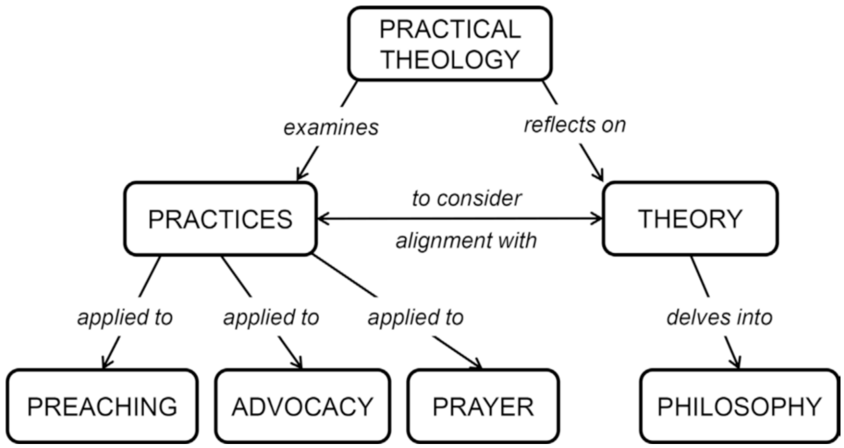

Figure 10. A student concept map of 'practical theology' demonstrating the emergence of enhanced explanatory power

INCREASING COMPLEXITY OR CLARITY

Figure 11 offers depictions of exemplar maps that may be typical of the 'good' and 'poor' maps that may be produced by students across the spectrum of examination results. Those poor maps that are associated with students with low exam marks tend to have few concepts and rudimentary links. In comparison, students who have excellent exam results can also draw poor maps as rated by various scoring protocols, but these maps tend to have concepts that represent the key ideas within a topic and are linked with phrases that reveal more about the level of student understanding and are dynamic and explanatory.

These observations suggest that concept mapping should be considered as more of a learning tool than an assessment tool – particularly where assessment requires a simple number or grade. What is clear from this is that bigger does not always mean better when evaluating concept maps. An economical presentation of data may indicate a greater level of expertise and may provide enough of a trigger for a student to recall the detail of the information. Clearly we need to adopt a more nuanced appreciation of the quality of student understanding. Students with little understanding can produce a map, but it may not be elegant or sophisticated. Cañas et al. (2015) consider maps according to levels of concept quality (Figure 12).

Concept maps that exhibit either poor quality of content or poor structure are designated as Level 1 maps (Figure 12). Those that do not fall below 'good' in either dimension would be designated as 'good maps', whilst those that exhibit excellent content and structure may be considered to be 'excellent maps'. According

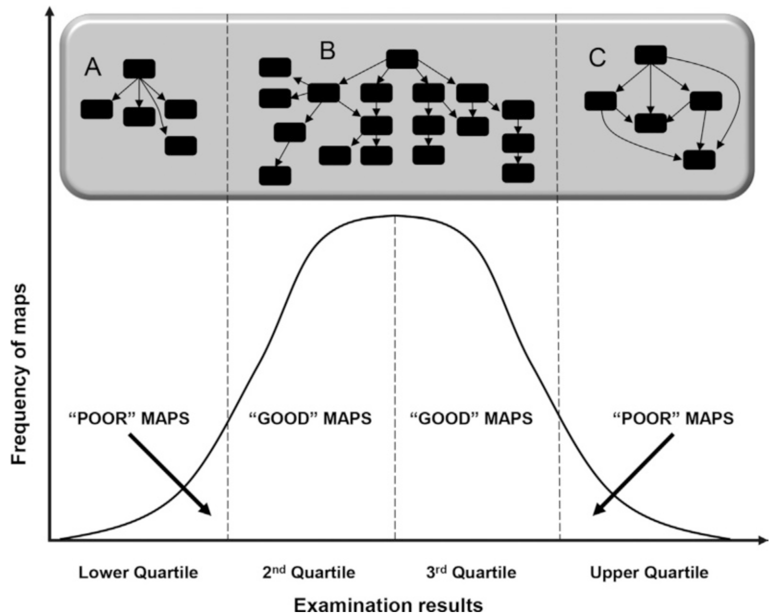

Figure 11. Distribution of maps across final exam results with exemplar map morphologies inset (From Kinchin, 2014; redrawn and modified from Johnstone & Otis, 2006)

to Cañas et al. (2015), for maps to be considered excellent they should also exhibit additional qualities:

Excellent maps are concise: just like an essay that rambles on and on about things that are beyond the scope of the title, a map that just includes everything that might be vaguely associated with the focus question is not helpful. Finding enough information is not always the criterion by which excellence is judged – deciding which information to exclude is just as important. Clariana and Taricani (2010) have commented that students who may include a lot of correct information in their maps may not always include the most important terms or place them in the most appropriate position in the map. So in order for excellent maps to be concise, the mapper has to evaluate the information to decide on it inclusion or exclusion. It is essential to make clear the teacher expectations of the outcomes of a mapping exercise to students. If students think that the goal is to include every possible piece of related information in their map, they will be overwhelmed by the volume of potential content and be deterred from further exploring the potential of concept mapping to support their learning (Bentley, Kennedy, & Semsar, 2011).

Excellent maps exhibit clarity: The purpose of a map is to convey an idea. If the ideas are so cluttered and congested that they become lost in the crowd, the message is lost. The map needs to present the author's message clearly in order to

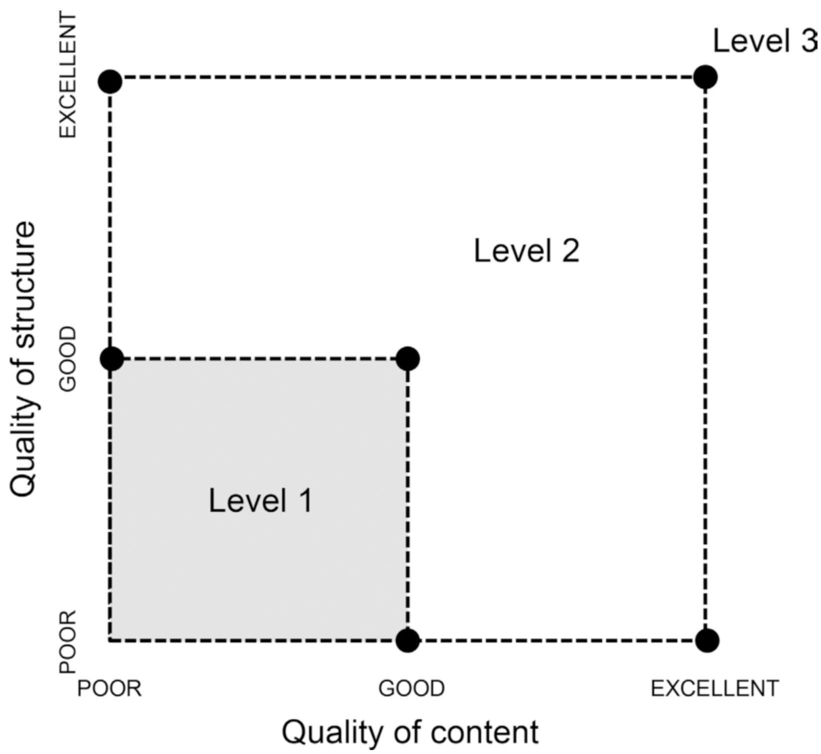

Figure 12. Levels of concept map quality (After Cañas, Novak, & Reiska, 2015)

communicate it well to the reader. This means that concepts should be clustered appropriately to avoid the linking arrows from crossing over each other.

Excellent maps are explanatory: If the map is purely descriptive then it does not provide any explanatory power. Maps that are pictorial representations of lists can fail to demonstrate any deep understanding. Whilst 'elegance' may appear to be a rather spurious and indefinable aim for a mapping exercise, it is evident when observing large numbers of maps that elegance of design often accompanies clarity of expression.

Excellent maps are balanced: Maps that exhibit branches that are of wildly unequal sizes are probably reflecting the bias or selective knowledge of the author. Unless there is good reason to produce an unbalanced map, selection of the higher order concepts should successfully produce a balanced map. The suggestion is that an unbalanced map either shows incomplete knowledge of a subject, or results from the selection of inappropriate higher concepts and should be reconsidered.

Excellent maps are appropriate for the intended audience: If the map is intended for a general audience, then use of highly specialised technical terminology is probably not helpful in terms of clarity or explanatory power. Alternatively, a very specialist audience would be put off by a map that uses colloquialisms.

Thus we can see that the exemplar map morphologies, A, B & C (included in Figure 11) can be mapped against the three levels considered by Cañas, Novak and Reiska (2015). The 'poor' maps in the lower quartile (A) tend to have a very simple structure and the number of concepts is small so unless they have been carefully chosen and linked with particularly good explanatory labels these are likely to be poor maps. The maps in the 2nd and 3rd quartiles (B) are those that have typically been labelled as 'good' maps. But these are rarely excellent maps as they often fall down in not being concise, clear or explanatory. Very often these are 'exploratory' rather than explanatory. In the literature, these maps typically gain high scores that reward the quantity of knowledge through the acquisition of information (demonstrating a good memory) rather than the quality of understanding that may demonstrate the ability to manipulate and transform information. Those maps in the upper quartile (C) have often been 'measured' as being 'poor' maps as they do not score highly in many of the quantitative rubrics. However, depending on the content and the nature of the links, these may be excellent maps if they conform to the dimensions discussed above.

Approaches that give the mapper maximum freedom in terms of content and structure are most likely to offer the greatest learning potential (Cañas, Novak, & Reiska, 2012). However, they will also produce the greatest diversity of maps within a class and will create work for the teacher/researcher if they need to be analysed and evaluated. Attempts to standardize maps by restricting the choice of concept labels to be used, or by providing a skeletal framework for the map construction will reduce the degree of diversity. This will make analysis easier, but may reduce the richness of the data and may reduce the maps' potential for supporting learning. There is therefore a tension between using concept maps as a research tool (where the focus is on analysis) and as a teaching tool (where the focus is on reflection). One of the problems encountered in mapping interventions is that mappers will not always conform to the 'accepted structural grammar' of Novakian concept maps (Novak, 2010) and will devise their own tacit rules of construction so that (for example) the major concept or focus question may not appear at the top of the page; concept labels may appear twice in a map or hierarchy may be ignored or ambiguous.

MAP TOPOGRAPHY

Comparison of map morphology is made difficult when difference is a result of variation in the instructions given to mappers. This is not just a question of aesthetics, the morphology of a student's map can be as important an indicator of their understanding as the content they have included or omitted. Methods to help in the analysis of map structure are therefore an important aspect of the value of maps in determining student understanding.

The difficulty in comparing maps that exhibit such diversity has been addressed by Buhmann and Kingsbury (2015) who have devised a method that considers map topography. They first re-draw the maps as 'content-free' skeletons by removing the concept labels and the linking phrases. The structure is then geometrically rearranged in a process they refer to as 'topological normalisation'. Within the process, the key concept (indicated as a square box) is placed clearly at the top of the map and the other concepts (indicated as round boxes) are arranged on levels that correspond to their distance from the key concept (see Figure 13). The transformation of maps in this way reveals the problems that some of the qualitative protocols have in identifying hierarchy and cross linkages. Within Figure 13 (i), it can be seen that the link between concepts 1–4 and between 1–3 appear to be cross linkages. This is clearly not the case in the normalised map in Figure 13 (ii), in which only the link between concepts 4–9 is seen as a cross link.

This topological normalisation procedure transforms the content-free concept map into a form which preserves the concept vertices and their links. By following a consistent and simple protocol, the ability to compare diverse presentation styles is enhanced. Buhmann and Kingsbury (2015) place the key concept at the top of the page, and concepts which are once, twice etc. removed from it are placed on subsequent hierarchical levels and linked as in their original form. Starting from the top, branches emerging from each concept vertex are ordered from left to right according to the following simple rules:

1. Place the deepest (longest) branch first.
2. For branches of equal length, place the branch with the largest total number of concepts first.
3. For branches with an equal number of concepts, place the branch with the largest number of longest sub-branches first.
4. For branches with an equal numbers of such sub-branches, place the branch whose uppermost concept has the largest number of sub-branches first.
5. For branches with equal numbers of sub-branches of the uppermost concept, place the branch with the largest number of cross-links first.

Where maps are not normalised in the manner suggested, and main concepts are allowed to be drawn centrally rather than above subordinate concepts (e.g. Mendonça & Silveira, 2016), it is not clear if the idiosyncrasies observed are representative of differences in understanding of the concepts, or just idiosyncrasies in the application of a visual grammar. In such instances it is difficult to visualise trends in developing understanding. Buhmann and Kingsbury (2015) claim that normalisation lays the foundation for the analysis of map morphologies which is not based on the mappers' idiosyncrasies. Through this process they have identified a number of common map types (Figure 14):

i. *Broad*: multiple branches from the key concept with little cross linking.
ii. *Deep*: multiple chains emanating from the key concept.

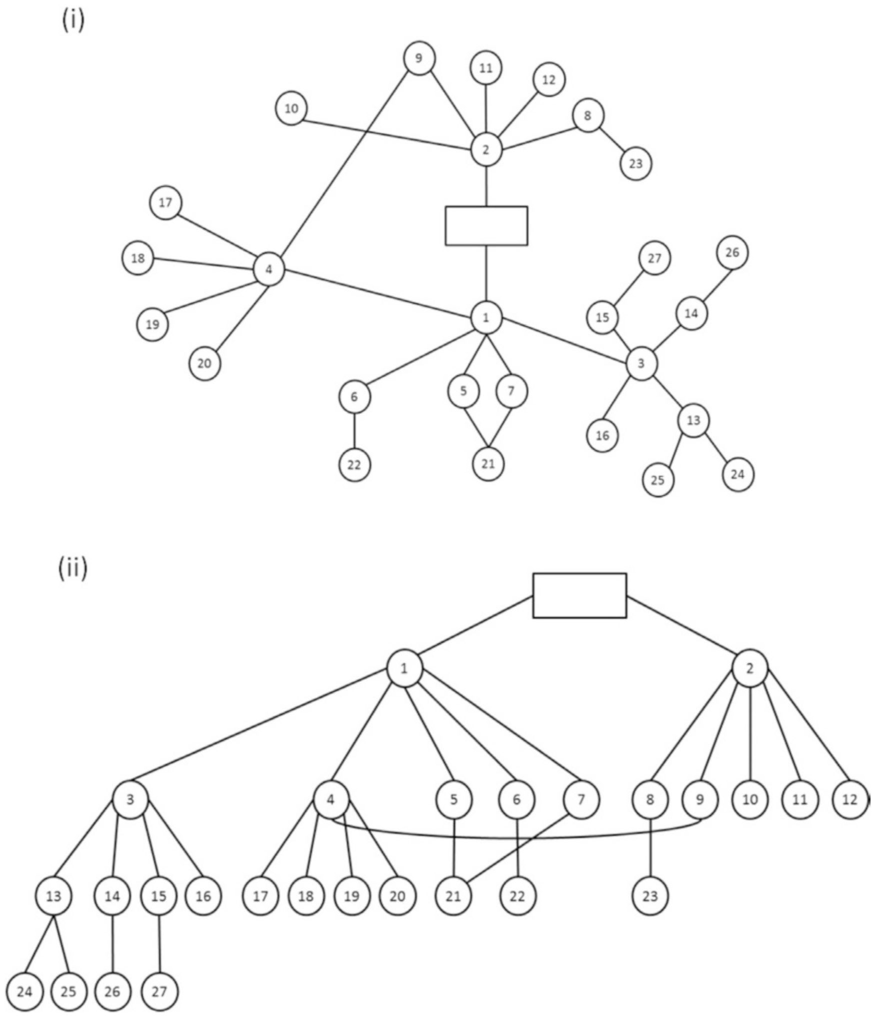

Figure 13. Geometrical rearrangement of content-free maps. (i) Content-free concept map with the concepts numbered to illustrate their repositioning in (ii) the topologically normalised version (From Buhmann & Kingsbury, 2015)

iii. *Imbalanced*: some chains are much more developed than others.
iv. *Disconnected*: segments have no link to the key concept.
v. *Interconnected*: forming an often messy network
vi. *Normal*: balanced structure that is well-connected; not dominated by multiple branches or multiple chains and features only significant cross links that do not obscure the overall structure.

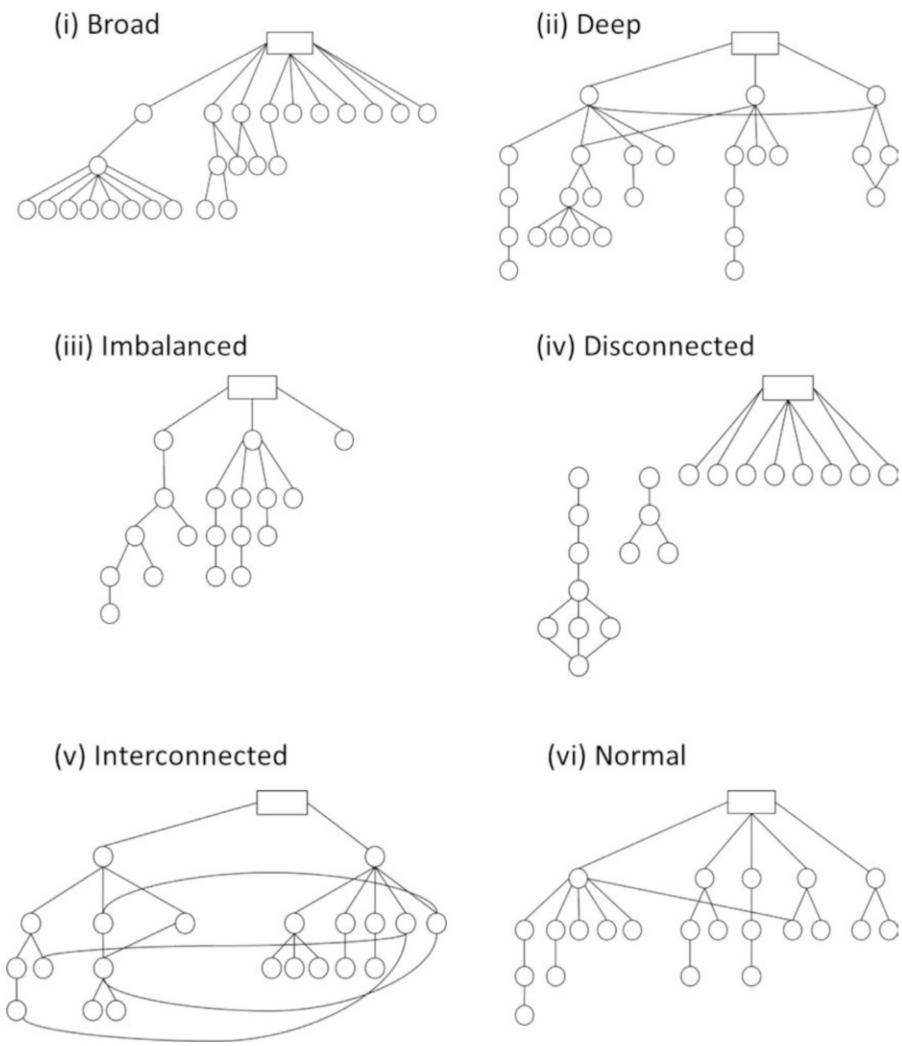

Figure 14. Example student concept maps illustrating common morphological classes in topologically normalised concept maps (From Buhmann & Kingsbury, 2015)

It is probably among these 'normal' maps that Cañas, Novak and Reiska (2015) would be looking for those that feature characteristics of excellence.

CONSISTENCY IN MAPPING

It is not just the learners/mappers who will apply arbitrary rules to their maps. In many of the research reports that are available in the literature, one finds comments where authors have tried to explain their research approach, but which are unjustifiable in educational terms. For example, Schmid and Telaro (1990: 80) explain how in the classes they were studying the '*instructor introduced content in the normal fashion [mainly lecturing] and, at the appropriate point, set aside time for each student to create a map of the specified content*.' The evident conflict between the traditional transmissive teaching model exemplified by lectures, and the constructivist basis of concept mapping is not recognised within this report. This is typical of many interventions that have attempted to stimulate classroom change through the implementation of concept mapping without due consideration of the environment where the intervention is being introduced. Similarly, Lehman, Carter and Kahle (1985: 669) describe how researchers have attempted to isolate or bracket out key factors in the classroom, such as the role of the teacher which they considered not to be '*significant influences*' in their study. More rigorous observations have shown teachers to be one of the strongest influences in the classroom (e.g. Reiss, 2000). Researchers are now recognising the intricacies of the classroom such that they cannot be seen as laboratories where all the variables can be controlled, but are more like ecological fieldwork in which the complexity can only be modelled, not controlled.

In order to avoid some of the weaknesses within the literature, the following recommendations are offered by Kinchin (2014) to guide the consistent development of future concept mapping interventions:

- Concept mapping should be used in compatible curriculum settings that reflect the constructivist underpinnings of the tool. It is important that the concept mapping tool is epistemologically aligned with the context in which it is set. If the teaching and the assessment regimes within a curriculum are intent on transmitting fixed information from teacher to student, then the potential utility of concept mapping is lessened. There must be room in the curriculum for students to visualise personal understanding if the tool is to be helpful. Concept mapping should be used where assessment regimes are focussed on meaningful learning and not memorization and recall.
- Concept mapping should be used as a learning tool, 'directing' the search for information, not 'ending' it (Wexler, 2001). If the expert concept map represents the answer to be memorised by students then the curriculum intent is non-learning (Kinchin, Lygo-Baker, & Hay, 2008) rather than meaningful learning (Novak, 2010). Possible pathways to meaningful learning must be recognised if concept mapping is to play an active part in the students' development.
- Teachers/researchers should have clear instructional objectives for the use of concept mapping that need to be conveyed to students. It is not helpful to students to simply deposit concept mapping as an activity within the teaching scheme unless there is a clear aim in doing so. Teachers need to be clear regarding what the benefits of a concept mapping activity might be, and should share this with their students.

- The degree of freedom afforded students in a concept mapping intervention should be justified and explicit. Students may be presented with a blank sheet of paper or with a list of concepts to link. Either approach has validity, depending what it is that the teacher is hoping to achieve (Cañas, Novak, & Reiska, 2012).
- The structural grammar used within a concept mapping intervention should be representative of the discipline. It is only sensible to insist that students construct hierarchical concept maps if the structure of the discipline being mapped is indeed hierarchical. It is, therefore, important to determine the structure of the discipline before asking students to map it (Kinchin, 2011; Donald, 2002). It should also be noted that a single map may not be adequate in representing the structure of applied sciences, and that sequential mapping over time may be required to observe changes in understanding (Kharatmal & Nagarjuna, 2013; Kinchin, 2013; Wu & Wang, 2012).
- Concept mapping should be combined with other learning strategies such as retrieval practices, collaborative learning, dialogue, and feedback. Concept mapping is most effective as a learning tool when combined with complementary activities to enhance the learning environment (e.g. Francisco et al., 1998). Students' interactions with concept mapping will be personal and idiosyncratic, with some students requiring more scaffolding and supplementary learning tools than others in order to gain the most from concept mapping activities.

IN CONCLUSION

The aim of producing excellent concept maps is not an exercise in academic vanity. Indeed, the production of a beautiful final map is usually not be the point of the mapping exercise as it is really the cognitive engagement with the concepts, i.e. a significant educational experience (as described by Hinchliffe, 2011) rather than an artefact of assessment that is more important. This is why many colleagues refer to 'concept mapping' as a process rather than 'concept maps' as outcomes. However, after expending considerable effort of their maps, many students and teachers are keen to keep them, and (in fairness) they may offer a future focus for further reflection. Excellent maps, as determined by the various dimensions explored above, will provide greater utility in supporting development of the teaching environment in which the expert student can develop. The use of poor maps that lack explanatory power is not helpful in developing the expert student and so it is important to clarify the characteristics that define excellent maps before colleagues investigate their use in inappropriate ways and then complain that concept maps are not helpful. There is some conceptual slippage in the published literature in which the term 'concept map' has been used too loosely and without the adequate theoretical context provided by the work of Ausubel (2000) or Novak (2010).

We will still find papers in which the authors do not adequately distinguish between concept maps and mind maps (e.g. Pudelko et al., 2012), tools which have different properties and different uses (Eppler, 2006; Davis, 2011). Research papers that use poor concept maps as exemplars suggest teaching that can at best support rote learning rather than meaningful learning because they lack key information such as linking phrases (e.g. Trelease, 2014), or they attempt to be too comprehensive and lose clarity because they are not sufficiently concise (e.g. Berglund, 2015). It is important to be precise and consistent with the use of terms if we are to develop a shared understanding of the significance of any tool in the visualisation of knowledge structures for the development of expert students. Finally, mappers need to appreciate that selecting content to be mapped and placing the nodes on the page is just the first stage in producing an excellent concept map. Counting concepts is not a good indicator of understanding. It should be the relations and interactions between ideas that serve as the unit of analysis when assessing student understanding (Semetsky, 2008).

NOTES

1. The term 'page' is used to refer to the area in which a concept map is constructed. However, it is acknowledged that for colleagues who are constructing their concept maps using software such as cmap tools, the term 'screen' may be more appropriate.
2. The term 'box' is used to describe the areas within a concept map that form the nodes on the map. For those colleagues who are using sticky Post-it notes to construct their maps, each box will be equivalent to a single Post-it note.

REFERENCES

Ausubel, D. P. (2000). *The acquisition and retention of knowledge: A cognitive view*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Bentley, F. J. B., Kennedy, S., & Semsar, K. (2011). How not to lose your students with concept maps. *Journal of College Science Teaching*, *41*(1), 61–68.

Berglund, A. (2015). What's in a word? Concept mapping: A graphical tool to reinforce learning of epidemiological concepts. *Journal of Epidemiology and Community Health*, *69*(12), 1232–1236. doi:10.1136/jech-2014-205068

Buhmann, S. Y., & Kingsbury, M. (2015). A standardized holistic framework for concept map analysis combining topological attributes and global morphologies. *Knowledge Management & E-Learning*, *7*(1), 20–35.

Cañas, A. J., Novak, J. D., & Reiska, P. (2012, September 17–20). Freedom vs. restriction of content and structure during concept mapping—possibilities and limitations for construction and assessment. In A. J. Cañas, J. D. Novak, & J. Vanhear (Eds.), *Concept maps: Theory, methodology, technology*. Proceedings of the Fifth International Conference on Concept Mapping (pp. 247–257), Valletta, Malta. Retrieved from http://cmc.ihmc.us/

Cañas, A. J., Novak, J. D., & Reiska, P. (2015). How good is my concept map? Am I a good Cmapper? *Knowledge Management & E-Learning*, *7*(1), 6–19.

Cannella, G. S., & Reiff, J. C. (1994). Individual constructivist teacher education: Teachers as empowered learners. *Teacher Education Quarterly*, *21*(3), 27–38.

Clariana, R. B., & Taricani, E. M. (2010). The consequences of increasing the number of terms used to score open-ended concept maps. *International Journal of Instructional Media*, *37*, 218–226.

Crandall, B., Klein, G., & Hoffman, R. R. (2006). *Working minds: A practitioner's guide to cognitive task analysis*. Cambridge: MIT Press.

Davis, M. (2011). Concept mapping, mind mapping and argument mapping: What are the differences and do they matter? *Higher Education*, *62*, 279–301.

Donald, J. G. (2002). *Learning to think: Disciplinary perspectives*. San Francisco, CA: Jossey-Bass.
Eppler, M. J. (2006). A comparison between concept maps, mind maps, conceptual diagrams, and visual metaphors as complementary tools for knowledge construction and sharing. *Information Visualisation*, *5*, 202–210.
Francisco, J. S., Nicoll, G., & Trautman, M. (1998). Integrating multiple teaching methods into a general chemistry classroom. *Journal of Chemical Education*, *75*(2), 210–213.
Gamache, P. (2002). University students as creators of personal knowledge: An alternative epistemological view. *Teaching in Higher Education*, *7*(3), 277–294.
Hinchliffe, G. (2011). What is a significant educational experience? *Journal of Philosophy of Education*, *45*(3), 417–431.
Johnstone, A. H., & Otis, K. H. (2006). Concept mapping in problem based learning: A cautionary tale. *Chemistry Education Research and Practice*, *7*, 84–95.
Kharatmal, M., & Nagarjuna, G. (2013). Representing change using concept maps. In G. Nagarjuna (Ed.), *Proceedings of epiSTEME 5 – International conference to review research on science, technology and mathematics education*. India: Cinnamonteal.
Kinchin, I. M. (2001). If concept mapping is so helpful to learning biology, why aren't we all doing it? *International Journal of Science Education*, *23*(12), 1257–1269.
Kinchin, I. M. (2011). Visualizing knowledge structures in biology: Discipline, curriculum and student understanding. *Journal of Biological Education*, *45*(4), 176–182.
Kinchin, I. M. (2013). Concept mapping and the fundamental problem of moving between knowledge structures. *Journal for Educators, Teachers and Trainers*, *4*(1), 96–106.
Kinchin, I. M. (2014). Concept mapping as a learning tool in higher education: A critical analysis of recent reviews. *The Journal of Continuing Higher Education*, *62*, 39–49.
Kinchin, I. M., Lygo-Baker, S., & Hay, D. B. (2008). Universities as centres of non-learning. *Studies in Higher Education*, *33*(1), 89–103.
Lehman, J. D., Carter, C., & Kahle, J. B. (1985). Concept mapping, vee mapping, and achievement: Results of a field study with black high school students. *Journal of Research in Science Teaching*, *22*(7), 663–673.
Mendonça, C. A. S., & Silveira, F. P. R. A. (2016). Teaching parasitology with concept maps in laboratory lessons for teacher education courses. *American Journal of Educational Research*, *4*(3), 254–263.
Miller, N. L., & Cañas, A. J. (2008). Effect of the nature of the focus question on presence of dynamic propositions in a concept map. In A. J. Cañas, P. Reiska, M. Åhlberg, & J. D. Novak (Eds.), *Proceedings of the 3rd international conference on concept mapping*. Tallinn, Estonia & Helsinki, Finland.
Moreira, M. M. (2012). *Freedom to teach and learn literature: The use of concept maps*. Bloomington, IN: Palibrio.
Nesbit, J. C., & Adesope, O. O. (2006). Learning with concept and knowledge maps: A meta-analysis. *Review of Educational Research*, *76*, 413–448.
Novak, J. D. (1993). Human constructivism: A unification of psychological and epistemological phenomena in meaning making. *International Journal of Personal Construct Psychology*, *6*, 167–193.
Novak, J. D. (2010). *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations* (2nd ed.). Oxford: Routledge.
Novak, J. D., & Cañas, A. J. (2006). The origins of concept maps and the continuing evolution of the tool. *Information Visualization Journal*, *5*(3), 175–184.
Novak, J. D., & Cañas, A. J. (2007). Theoretical origins of concept maps, how to construct them, and uses in education. *Reflecting Education*, *3*(1), 29–42.
Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.
Novak, J. D., & Musonda, D. (1991). A 12-year longitudinal study of science concept learning. *American Educational Research Journal*, *28*(1), 117–153.
Pudelko, B., Young, M., Vincent-Lamarre, P., & Charlin, B. (2012). Mapping as a learning strategy in health professions: A critical analysis. *Medical Education*, *46*, 1215–1225.
Reiss, M. J. (2000). *Understanding science lessons: Five years of science teaching*. Buckingham, UK: Open University Press.

Safayeni, F., Derbentseva, N., & Cañas, A. J. (2005). A theoretical note on concepts and the need for cyclic concept maps. *Journal of Research in Science Teaching*, *42*(7), 741–766.

Salmon, D., & Kelly, M. (2015). *Using concept mapping to foster adaptive expertise: Enhancing teacher metacognitive learning to improve student academic performance*. New York, NY: Peter Lang.

Schmid, R. F., & Telaro, G. (1990). Concept mapping as an instructional strategy for high school biology. *Journal of Educational Research*, *84*(2), 78–85.

Semetsky, I. (2008). Re-reading Dewey through the lens of complexity science, or: On the creative logic of education. In M. Mason (Ed.), *Complexity theory and the philosophy of education* (pp. 79–90). Oxford: Wiley-Blackwell.

Trelease, J. (2014). Using concept mapping to prepare for the foot care certification examination. *Journal of Wound Ostomy and Continence Nursing, 41*(1), 84–85.

Wexler, M. N. (2001). The who, what and why of knowledge mapping. *Journal of Knowledge Management*, *5*, 249–263.

Wu, B., & Wang, M. (2012). Integrating problem solving and knowledge construction through dual mapping. *Knowledge Management & E-Learning*, *4*(3), 248–257.