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Ian M. Kinchin
University of Surrey, United Kingdom

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Ian M. Kinchin, University of Surrey, United Kingdom
i.kinchin@surrey.ac.uk

Abstract
A concept map provides a 'snap shot' of a student's understanding that is frozen in time by drawing it out on paper or on a computer screen. However, to represent the dynamic state of student learning, concept maps either need to emphasise dynamism (through the phrases that are chosen to act as links within the propositions that form the map), or need to be viewed as a single perspective on a more complex situation that can only be fully appreciated by considering movement between knowledge structures (e.g. through sequential mapping over time, or by indicating relationships between map structures that represent complementary learning contexts). The recognition of the importance of movement between knowledge structures needs careful management, whether teaching is conducted as a face-to-face activity or (increasingly) as a digital/online activity. Existing models of e-learning development (such as the TPACK model) can be modified to accommodate a multiple perspectives view. When the purpose of teaching is the promotion of students' ability to move between knowledge structures (rather than acquiring a single structure), the purpose of producing a concept map changes and becomes part of a wider dynamic process of learning, rather than providing a static record of what has already been learnt.

Resumen
Un mapa conceptual ofrece una "instantánea" del entendimiento de un estudiante, la cual se congela en el tiempo al dibujarla sobre un papel o en una pantalla de ordenador. Sin embargo, para representar el estado dinámico del aprendizaje de los estudiantes, los mapas conceptuales necesitan enfatizar dinamismo (a través de las frases que son elegidas para actuar como enlaces dentro de las proposiciones que conforman el mapa), o necesitan ser vistos como una perspectiva única de una situación compleja que sólo puede ser apreciada en su totalidad al considerar el movimiento entre estructuras de conocimiento (por ejemplo, a través de la construcción de mapas secuenciales en el tiempo, o indicando las relaciones entre las estructuras del mapa que representan contextos de aprendizaje complementarias). El reconocimiento de la importancia del movimiento entre estructuras de conocimiento requiere un manejo cuidadoso, sea cual sea la enseñanza se lleve a cabo como una actividad cara-a-cara o (como ocurre cada vez más) como una actividad digital / en línea. Los modelos existentes de desarrollo de e-learning (tales como el modelo TPACK) pueden ser modificados para acomodar una vista de perspectivas múltiples. Cuando el propósito de la enseñanza es el fomento de la capacidad de los estudiantes para moverse entre las estructuras de conocimiento (en lugar de la adquisición de una sola estructura), el objetivo de producir un mapa conceptual cambia y se vuelve parte de un proceso dinámico de aprendizaje más amplio, en vez de proporcionar un registro estático de lo ya aprendido.

Keywords
Complementary knowledge structures, qualitative analysis, structural transformation.

Palabras clave
Estructuras complementarias conocimientos, análisis cualitativo, transformación estructural.

1. Introduction

"*Moving from a linear structure to a hierarchical structure and back again is in some ways the fundamental educational problem*."
Novak and Symington (1982: 08)

This comment by Novak and Symington offers an important insight to the ways in which concept mapping may be used to support learning, and also offers a method of linking the educational theory that underpins concept mapping with other contemporary learning theories (Kinchin, 2012a). The important point to make is that this line from Novak and Symington starts with the word, '*moving*'. It is this movement that needs to be conveyed within concept maps if they are to address this '*fundamental educational problem*'.

There are numerous potential benefits to be gained from mapping knowledge (e.g. Wexler, 2001), but it cannot be assumed that they will all be realised in every intervention that employs maps. As Tzeng points out:

> "*concept maps with different strategic orientations may lead to the formation of different mental representations … therefore, instructors need to know exactly what they intend… to determine whether the design of their concept maps effectively conveys their instructional objectives*". Tzeng (2010: 143)

Therefore, there needs to be a clear rationale for mapping and the way it will be employed. Concept mapping can be implemented in a variety of ways that may allow the students or research subjects various degrees of freedom in terms of structure and content (Cañas *et al.*, 2012), with consequences for the resulting map structures. Restricting freedom (by determining concepts to be included or layout to be adopted) will give a higher degree of standardisation of maps, and this is more important when they are being used as a research tools as it allows maps to be compared. Development of maps in 'free form' may be more important when they are being used as a learning tool.

Concept maps can illustrate the difference between a student's emergent understanding and experts' agreed knowledge. However, unless the underlying structure of the discipline has been made explicit during a programme of instruction (e.g. Donald, 2002), there is no reason to suggest that the morphology of the student map should simply represent a smaller version of the expert map. There may be a 'tipping point' in a student's learning (possibly through the acquisition of a 'threshold concept' – Meyer and Land, 2003) where the acquired content may start to show some transformation towards the agreed expert structure.

Clariana (2010: 119) considers that the tasks involved in the creation of a concept map leave markers described as '*cognitive residue*' within the map. These include the *selection* and *grouping* of concepts; *identifying propositions* and *adding linking phrases* to show the meaning of the proposition and finally revising the map to reflect both the *structure of [the learner's] knowledge* and an *internalized graphic grammar*. The key is to get the right balance between the idiosyncratic nature of personalized knowledge construction in the form of an agreed visual grammar that is intelligible to others. However, as a note of caution, it is clear that students can be wrestling with the construction of new understanding whilst also 'testing' the grammar of the concept map, such that what may appear to an observer to be a mess may be a powerful learning tool for the student constructing the map (Johnstone and Otis, 2006).

Concept mapping seems to offer the most valuable contribution to student learning where the mapping task mirrors the actions undertaken to practise the discipline being studied (Di Carlo, 2006). So, for example, in the teaching of physiology, students who are encouraged to construct concept maps are actively integrating the components of the subject and identifying causal relationships between them in a way that also typically reflects the desired learning outcomes of a physiology course (Henige, 2012).

2. Complementary structures

Whilst there has often been a tendency to score maps to provide a clear and simple way of recording a student's progress, there needs to be some caution with this approach as the reduction of the rich insights to a student's learning offered by a map in this way has the potential to lose vital information. For example, studies that look only at the '*proportion of correct ideas produced in the concept map*' (e.g. Karpicke and Blunt, 2011: 773) fail to acknowledge that some concepts are more important than others in the construction of understanding (Mintzes and Quinn, 2007), or that students who may include a lot of correct information in their maps may not always include the most important terms or, indeed place those key terms in the most appropriate space on the map (Clariana and Taricani, 2010). It is also clear that students who produce 'poor' concept maps can fall equally into the first and fourth quartiles of normal assessment regimes (Johnstone and Otis, 2006). This is because some of the poor maps can indicate students have a weak grasp of the ideas under discussion whilst other (more knowledgeable students) can produce an apparently poor map as this may be sufficient for them to act as a 'set of keys' to retrieve information from their memory and support their reasoning strategies. This suggests that concept mapping may be viewed primarily as a learning tool rather than as an assessment tool (Johnstone and Otis, 2006). In most scoring protocols, there is an underlying assumption that bigger equals better. But with this starting point, one can be misled when expert maps can be smaller than novice maps of the same subject. This occurs because experts can select the key concepts and explanatory links that are economical in presentation. A more nuanced appreciation of student understanding that goes beyond the quantity of information recalled and requires an acknowledgement of the structure and quality of maps to complement the content that is included.

Qualitative analyses of concept maps have resulted in the proposal to consider them by reference to their gross morphology, as spoke, nets, chains (Kinchin, Hay and Adams, 2000) and cycles (Safayeni *et al*., 2005) figure 1. These structures have been shown to be indicative of particular learning orientations. Spokes tend to offer no more insight to understanding than a bulleted list and are often accompanied by static linking phrases. Chains appear to correlate with rote learning and tend to be learned as a complete sequence that is resistant to development. Networks seem to be most closely associated with meaningful learning, especially when the linking phrases are dynamic and explanatory. The cycles offer the greatest degree of dynamism and are often linked with iterative learning processes in which the meaning of concepts can evolve with each turn of the cycle. These structures each have their roles to play in student learning and they are not mutually exclusive as one structure may evolve into another over a period of time so that a spoke structure may develop into a chain or a network as the student's understanding is elaborated in response to further learning.

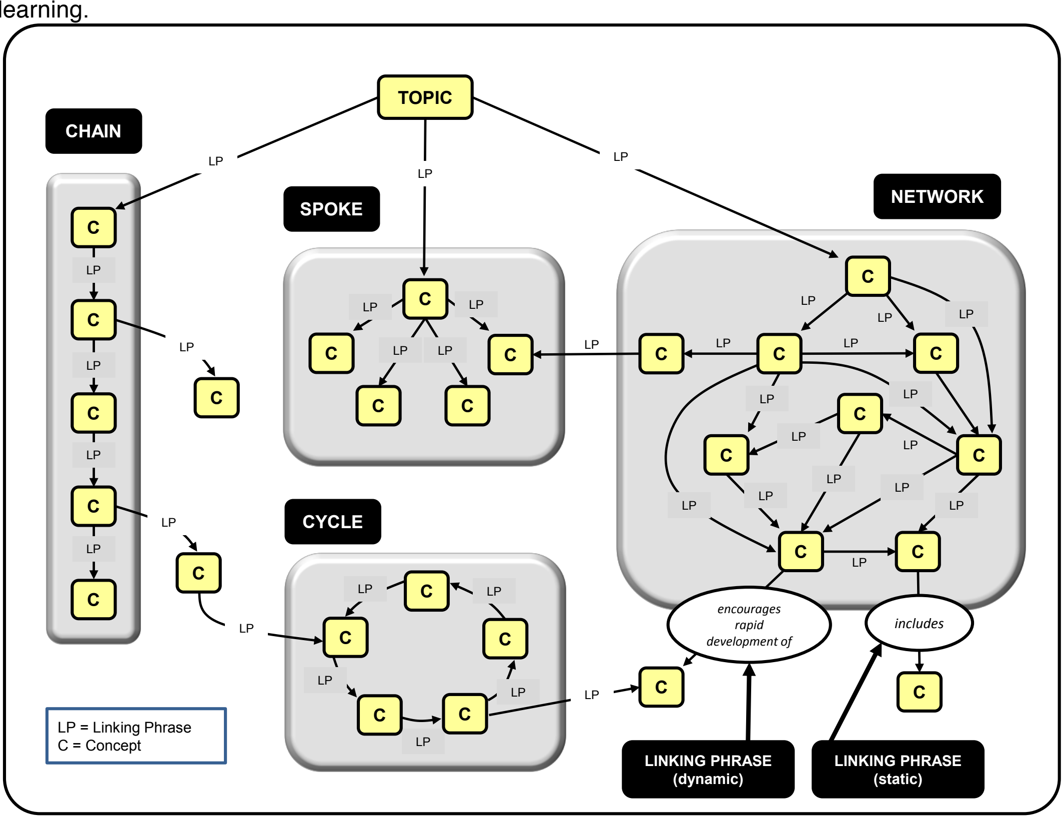

Figure 1: The features of concept maps that include chain, spoke, cycle and network morphologies (modified and re-drawn from Popova-Gonci and Lamb, 2012).

It is also clear that whilst some structures are more or less contextually appropriate in a given situation, the student needs to appreciate this and to construct understanding accordingly. With this perspective has emerged the idea of "*the expert student*" as "*one who recognises the existence and complementary purposes of different knowledge structures, and seeks to integrate them in the application of practice*" Kinchin (2011: 187). Part of this appreciation is concerned with the relationship between processes and products of learning (Kandiko and Kinchin, 2012), and the relationship between theory and practice.

The important distinction between procedural and conceptual knowledge has been explored by Schneider and Stern (2010) who analyse the various theoretical viewpoints on the causal interrelations between these kinds of knowledge: summarised as *unidirectional* (concepts-first or procedures-first), *bidirectional* (iterative) or *no causal relationship* (inactivation). Conceptual knowledge is usually viewed as general and abstract whilst procedural knowledge is seen as practical knowledge that is often automated and tied to specific problem types. Figure 2 shows how the procedural and conceptual components of understanding may be illustrated using concept maps. The top map (A) was produced by an expert in the field of dental anaesthesia. Here was can easily see what it is that she wants her students to be able to do (illustrated by the chain of yellow concepts on the left). But for the students to understand what they are doing and to be able to control this chain so that it may evolve over time, it is important that it is closely associated with an understanding of the process (summarised in the network of blue concepts on the right).

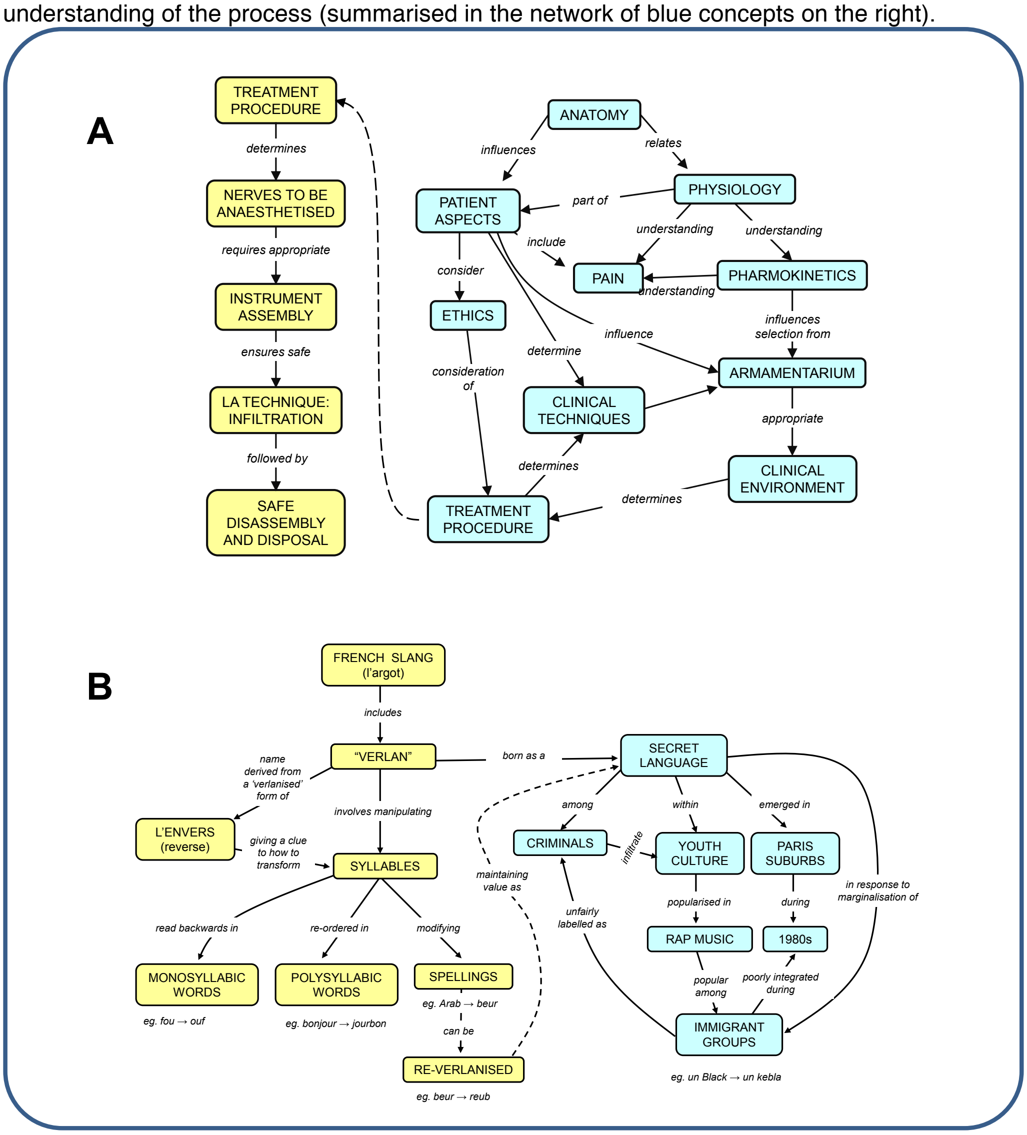

Figure 2: Complementary linear (yellow) and network (blue) structures can appear within a concept map, indicating the procedural and conceptual components of understanding. Part A: an 'expert' map of dental anaesthesia; Part B: a student map of French slang.

The lower map (B) was produced by a student during a lecture on French grammar. Here we can see the emergence of a similar dual structure in which the practice of French slang ('verlan') is illustrated by the yellow concepts on the left and the underlying social context for this language use is described by the network of blue concepts on the right. In comparing the two maps (A & B) we can see that the expert map (drawn by the dental teacher) has a clearer distinction between the procedural and the conceptual. The chain of practice (yellow) is well-rehearsed and made as simple as possible. This in an indication of expert practice in a context where speed of action is crucial. In contrast, her network of understanding is rich and tightly integrated as she has reflected upon her knowledge and her teaching in some depth. In comparison, the student's map of French grammar is not so well-developed in as much as the chain of practice (yellow) is not as simple (therefore, offering less certainty in use) and the network of understanding (blue) is not as highly integrated as the network in map A. This student has not had the same amount of time for consolidation and reflection as the expert – it was drawn during the lecture. Therefore, the map is not as well-developed, showing an emerging structure rather than an expert structure.

An additional reason for the greater level of distinction between the chain and the network in dentistry is that the elements of the chain (clinical practice) and the elements of the network (clinical science) are taught by different sets of teachers, at different times and in different physical spaces. This emphasises the separation. In the French class, however, the teaching of the chain and the network were undertaken by the same teacher within a single class – allowing the teacher to relate the two components for assimilation by the students. Kinchin and Cabot (2010) have claimed that one of the attributes of professional experts is that they are able to oscillate meaningfully between the linear and the hierarchical. Whereas practitioners can move between these structures in a seemingly automated manner, expert teachers need to be able to reflect on these transitions and provide ways to make them explicit and accessible for their students. Tsui (2009) has termed this '*practicalizing theoretical knowledge*' and '*theorizing practical knowledge*' and considered this ability to be one of the distinctive qualities of expert teachers.

3. Knowledge structures in the digital classroom

As an increasing proportion of teaching occurs within a digital/online environment, it is important to ensure that the pedagogical principles developed in face-to-face teaching are not lost or neglected as practice is transferred from analogue to digital settings, as the focus can be diverted from students to the computer technology they are using. The TPACK (Technology, Pedagogy and Content Knowledge) framework has been proposed by Koehler and Mishra (2009) as means to consider the interacting elements of technology, content and pedagogy in order to inform the development of technology-enhanced learning. This offers an excellent medium in which to consider the interactions of the key elements. The typical depiction of the TPACK framework as a two dimensional representation (i.e. length and width, but no depth) portrays a mono-layer of possible interactions between the three main elements (Figure 3):

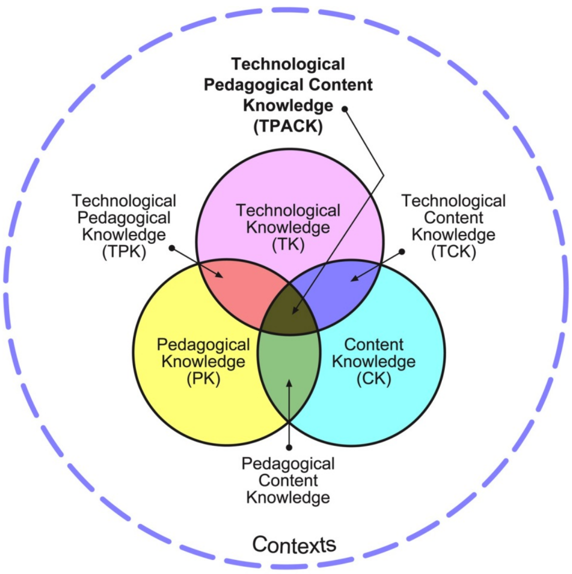

Figure 3: The TPACK framework (from http://tpack.org/ with permission)

Howard and Maton (2011: 193) comment on the TPACK framework as an example of '*models that list what knowledge is of, but which do not then analyse the forms taken by that knowledge'*. They go on to comment that '*what is required is a means of not only seeing knowledge but also moving beyond empirical descriptions of knowledge practices to analyse the principles underlying those practices*' (*ibid.*: 194). This perceived weakness of the TPACK model can be addressed by applying a knowledge structures perspective through concept mapping, which provides a mechanism to enhance the utility of the framework by revealing these underlying practices (Kinchin, 2012b).

A knowledge structures perspective suggests that the two-dimensional model represents only the surface view of the interactions between the three elements, concentrating on the linear structures that define them (i.e. the mechanisms and processes that are made public and recognizable by all concerned), and so blurring the relationship between procedural and conceptual knowledge. For example, the actors inhabiting each of the model segments (academic developers, e-technologists and teachers/researchers in the disciplines) are defined by their observable actions (academic development; production of technology solutions; delivery of content in the class). However, underpinning each of these characteristic actions (defined as *linear chains of practice* by Kinchin and Cabot, 2010), are knowledge bases that provide the understanding for the development for these actions (defined as *networks of understanding* by Kinchin and Cabot, 2010). If the surface view was the only level of the model, then interactions between the three areas would be difficult as a meaningful exchange of information is hindered by the linear nature of the knowledge structures involved – leading to a non-learning outcome (as described by Kinchin, Lygo-Baker and Hay, 2008). However, for each of the three sectors visible in the surface view of the TPACK model (Figure 3), there is another level that underpins those observable actions. This level is taken for granted by those who occupy a particular sector of the model (academic developer, e-technologist, teacher/researcher), but may be invisible to occupants of the other sectors, or to students. By making the underlying level of the model explicit to all, this issue may be overcome (Figure 4):

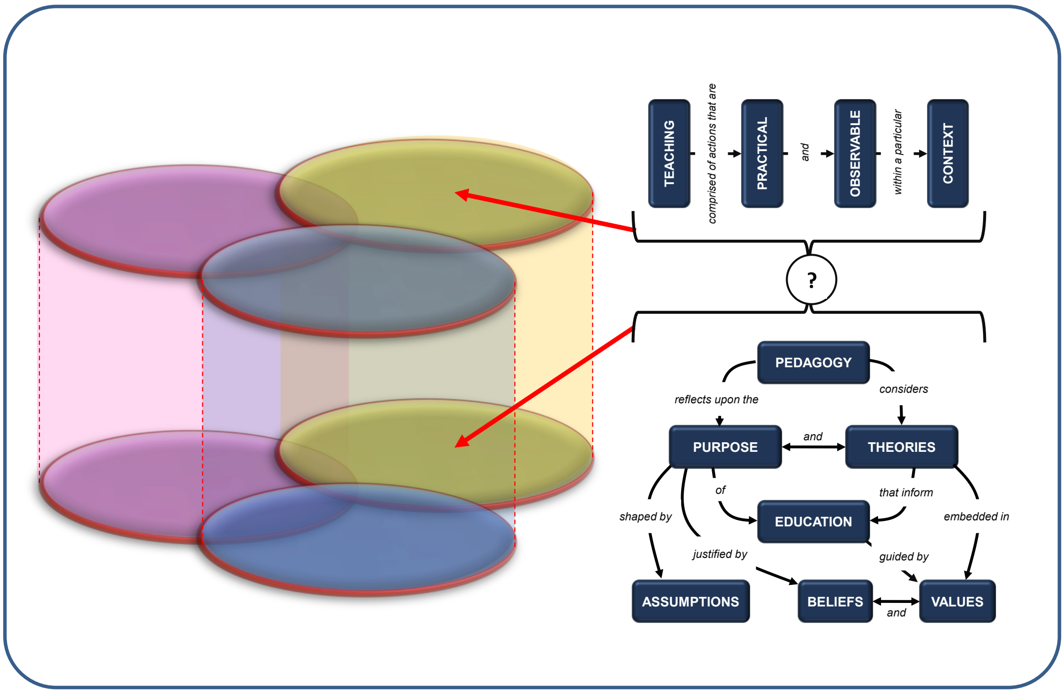

Figure 4: An oblique view of the TPACK framework to reveal the lower layer (composed of hierarchical networks of understanding) that is often obscured by the surface layer (composed of linear chains of practice). Structural components of the pedagogical knowledge section are shown as an example.

Within figure four, we can see that the circle representing pedagogical knowledge can be viewed as a bilayer. The top layer (usually visible to the outside observer and the focus of attention for colleagues working within a disciplinary area – Yiend *et al.*, 2012) consists of the procedural knowledge that consists of the linear practice of teaching. The underlying circle (often obscured from external view) consists of the underlying values, beliefs and assumptions that contribute to an understanding of pedagogy.

Adding this extra dimension to the TPACK model allows for the better alignment of the evolution of e-learning to other contemporary theories of learning and curriculum development such as Bernstein's sociology of education (e.g. Czerniewcz, 2010), Ausubel's assimilative learning theory (e.g. Kinchin, Lygo-Baker and Hay, 2008), and Meyer and Land's threshold concepts theory (e.g. Kinchin and Miller, 2012). This is achieved by considering the multiple perspectives that the authors cited above would describe respectively as, "*interactive discursive planes*" (Czerniewcz, 2010), or "*complementary knowledge structures*" (Kinchin, Lygo-Baker and Hay, 2008; Kinchin and Miller, 2012). It also re-asserts the underpinning role of pedagogy in the development of innovative teaching approaches (Kinchin, 2012a; 2012b). When TPACK is viewed in this way, it becomes apparent that its applicability goes beyond the subset of teaching that is often characterized as technology-enhanced learning, and its more general relevance to university teaching becomes apparent. The artificial separation of *e-learning* from *everything else* then becomes redundant as the implicit dominance of technology within the model gives way to the explicit recognition of the essential underpinning provided by pedagogy. This addresses the call made by Clegg, Hudson and Steel (2003: 51) to re-focus attention "*away from the functionality of e-learning environments back to the core relations between students and teachers*".

The previous lack of recognition of the underlying layer of the TPACK model also provides a possible explanation for the way in which e-learning has been reported to have failed to deliver the anticipated disruption of traditional teaching practices. For example, Blin and Munro (2008: 488) describe the dominant use of virtual learning environments (VLEs) to present, *"static", content-based resources such as web pages and lecture notes*', whilst Hemmi *et al*. (2009: 20) are critical of '*a conservative dependence on pre-digital metaphors, signs and practices*' in which the '*structural linear hierarchies of the commercial VLE relate to a logic associated with analogue writing technologies*'. When public linear discourses are seen to dominate the traditional discourse of non-learning (as described by Kinchin, Lygo-Baker and Hay, 2008), the conceptual, hierarchical knowledge structures that tend to be held more privately by stakeholders in the TPACK framework (teachers, e-learning technologists and academic developers) can be overlooked. However, the interaction between the linear and the hierarchical is where the observer is likely to find novel applications that will, in turn, provide the impetus for disruption that appears to have been absent from the application of many innovative ICTs in higher education (e.g. Conole *et al*., 2008).

Acknowledging the structure of the underlying layer of the TPACK model through concept mapping has implications not only for the design of e-learning materials, but also for modes of teaching and assessment. Teaching can no longer be seen as the transmission of a single perspective, but must support the students' conceptual movement between linear and hierarchical knowledge structures (as discussed by Novak and Symington, 1982). In the application of digital technologies to teaching, Kaipainen *et al.,* (2008: 477) concluded that a single perspective should be regarded as a '*transient'* and '*partial'* view of a complex environment, and that a '*more profound comprehension emerges in the course of an iterative process of exploring the data from alternative perspectives*'.

4. In Conclusion

Student learning does not occur in a vacuum. It has a context in which the student makes sense of what is going on. This is why 'controlled experiments' can be difficult to design in the field of classroom teaching. By controlling the environment to make it replicable, it is difficult to retain the ecological authenticity that enables educational research to impact upon classroom practice. The nature of the curriculum and the relationship between student and teacher is difficult to replicate between researcher and student. Where the fit is not acknowledged, the observed results gained can run against observations from authentic classroom practice (e.g. Karpicke and Blunt, 2011). The curriculum helps to provide this context, but in order for concept mapping to have a role in the students' learning, it must complement the way in which the curriculum is applied, and the assumptions that follow from that – in Wexler's terms, the '*who, what and why*' (Wexler, 2001). Piihl and Philipsen (2011) have used the conceptual lens provided by Gibbons *et al*. (1994) in their studies looking at the teaching of entrepreneurship. Piihl and Philipsen consider that the context-independent knowledge that students acquire in lectures (what they term the 'mode 1 curriculum') can be viewed as different from the context-dependent knowledge created through the solving of practical problems ('mode 2 curriculum') in terms of the 'theory-of-application' employed by each. By this they mean that in mode 1 the teacher acts as expert, based on the premise that they hold the appropriate knowledge to be taught. However, in mode 2, the teacher needs to be able to construct the knowledge that is necessary for a given situation and should be seen more as a change agent.

Moving from mode 1 to mode 2 is analogous to the description of 'crossing the threshold from discipline expert to discipline practitioner', as described by Behari-Leak and Williams (2011).

It would seem that the mode 1 curriculum would be representative of the decontextualized research environment in which the students are encouraged to produce concept maps that are static representations of acquired knowledge, whereas the mode 2 curriculum would be a more dynamic environment in which the maps are seen as tools to aid the construction of understanding. The latter would seem to fit best with the constructivist underpinnings of concept mapping (Novak and Cañas, 2007), where map morphology and linking phrase quality are key indicators of active learning (see Figure 1). The 'mode 2' curriculum mode aligns with Wexler's assertion that, "*knowledge maps must direct the search for information, not end it*" (Wexler 2001: 251).

Clariana (2010: 128) warns against '*training participants to create hierarchical concept maps, whether the domain organization is hierarchical or not*' as this will '*alter the obtained knowledge structure improperly towards hierarchical relationships*', and goes on to comment that this could '*devastate the relationship between the artefact obtained and the participant's actual knowledge structure'*. Whilst concept mapping rules offer helpful guidelines and help to maintain consistency of presentation to assist in analysis for research purposes, they should not be used to inhibit expression of understanding among learners or to create conflict with disciplinary ways of thinking. The structure of the discipline must be acknowledged when observing maps from various contexts. Indeed, where the learning context is 'interdisciplinary' in nature (such as in the clinical sciences) it should be anticipated that a possible duality of structures may co-exist (as seen in Figure 2A), and that this duality may actually define that particular area of study/practice (e.g. Anderson and Schönborn, 2008; McMillan, 2010) as theory and practice combine to form disciplinary expertise.

In their consideration of the complex processes involved in learning through problem-solving, Wu and Wang (2012) propose a dual mapping learning environment that may serve as a visual affordance for improving problem solving and the underlying knowledge construction process – as well as the transformation between the two. Whilst Wu and Wang (2012) consider complementing the concept mapping of knowledge structure with argument mapping to document problem-solving behaviour, the process of reciprocation between the processes is similar to the combination of problem-based learning (PBL) and concept mapping to relate the practice of physical education and the underlying concepts of physiology (reported by Baena-Extremera and Granero-Gallegos, 2012), and the chains of practice and networks of understanding produced by concept mapping that are described as components of professional expertise by Kinchin and Cabot (2010). The key point that is common to these studies is the structural transformation that links the two components (Kinchin and Miller, 2012), as predicted thirty years earlier by Novak and Symington (1982).

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