RESEARCH REPORT

A three-tier system for assessing concept map links: a methodological study

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A novel method is described for analysing concept maps for research and analysis purposes. The coding system rates the use, the stability, and the complexity of each link, which is a unique way of representing students' knowledge. The analysis scheme affords a look at how students may integrate new knowledge into their existing structures and may be used for assessment purposes or research on how students learn. This coding system was successfully applied to a sample of 56 complex concept maps that had been generated from student interviews on the topic of chemical bonding. The coding system is of particular use when analysing complex concept maps with a large number of concept nodes and links. The system described here was also particularly useful for assessing complex, non-hierarchical concept maps.

Introduction

Concept maps visually represent students' knowledge structures and meanings in a particular knowledge domain. Initially designed by Novak and Gowin (1985) and Novak (1990) to represent how students linked hierarchical material together in the domain of biology, concept mapping is becoming an increasingly important technique for analysing student understanding in other disciplines.

Concept maps are built by placing terms, which represent the concepts to be mapped, in structures called nodes. The nodes are then linked together into propositions to show how students connect or link the concepts. For an example concept map generated from this study, see figure 1. Note that individual concepts are connected together with propositions, which are represented by arrows. The arrow indicates the directionality of the link. The directionality and the connecting propositions indicate how the student conceptualized the material. The propositions illustrate the contextual relationship of the concepts to each other. The words over the arrow represent how the student connects concepts together.

Concept mapping, although originally conceived for biology education (Novak 1981), has been a useful tool for all science education. Concept mapping grew out of the cognitive learning work of Ausubel (Malone and Dekkers 1984). The use of concept maps as a learning tool compliments the constructivist model of learning, in which students build their own understanding from the material presented in class (von Glasersfeld 1991). In fact, concept maps have been traditionally used by
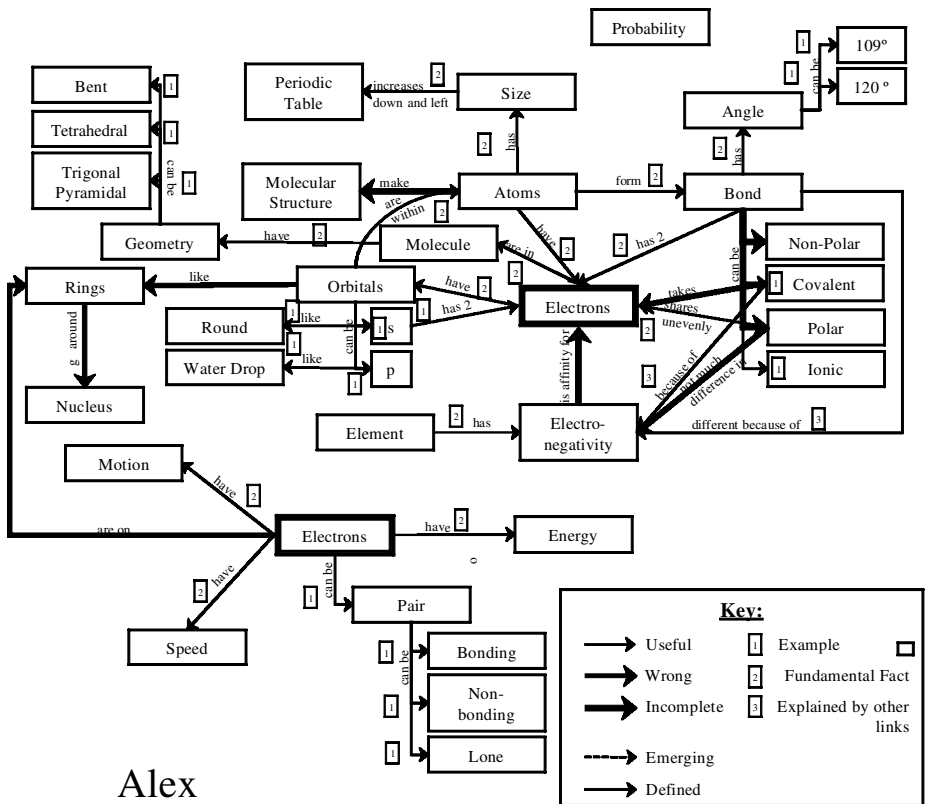
Figure 1.   An example concept map, showing how each link was colour-coded and how the levels of utility were addressed. The 'Electrons' node is emphasized because it appears twice in the map. This was done for pragmatic reasons: not all the nodes that connected to 'Electrons' would fit around it.

those subscribing to the constructivist model of learning in an attempt to under-stand and model how students learn (Cliburn 1990). There are several proponents of concept maps who state that they capture students' true understanding of con-cepts (Ault 1985). For more detailed references dealing with the uses of concept mapping, see Al-Kunifed and Wandersee (1990).

Research in other areas has shown that typical students do not have a vast store of knowledge. What knowledge they do have is typically disjointed and not well-connected (Fowler and Bou Jaoude 1987). In contrast, successful learners have well developed knowledge structures that are interconnected. This makes the con-cept map an invaluable tool for representing what knowledge students have acquired over a long period of time. Indeed, concept maps are the ideal tool for this purpose, given Ausubel's beliefs that students' pre-existing cognitive struc-tures are the anchor for all new material and that concepts derive their meanings from links with other concepts (Arnaudin et al. 1984).

Concept maps have the ability to represent different aspects of students' understandings (Shavelson et al. 1993). The nodes in the concept map represent

the initial concepts that are already present in students' minds. Just as important, if not more so, are the links that students make between nodes. This is the contextual knowledge that students have (Shavelson *et al*. 1993). Finally, these concept maps may be compared from different instructional levels to help determine what types of changes take place. These changes in the structure of the concept maps represent changes in students' conceptual frameworks, as evidenced by the work of Regis *et al*. (1996). In their study, high school level general chemistry students were first trained on how to use concept maps. These students were then asked to generate concept maps of their understanding of chemical electrolysis using a fixed number of given terms during the course of two interviews: one at the beginning of the unit and one at the end. In 75% of the cases, students had a dramatic change in conceptual understanding of the material, as evidenced by their concept maps. This procedure was carried out for first through third year high school chemistry students and conclusions about the conceptual change of the students with instruction as well as instructional level were drawn.

All of the applications mentioned here have focused on using concept maps to assist student learning, maximize the utility of the method of concept mapping so that students obtain the most out of it, or identify student misconceptions in one concept area. Very little, however, has been done on using concept maps to investigate how students link multiple concepts together from a chemistry course. Concept maps are uniquely suited to an investigation of students' links between concepts, as they are both a qualitative and quantitative method for assessing students' links between ideas.

Constructivist theory

As concept mapping is based on the constructivist model of learning, the theory bears directly on how the investigation was implemented, conducted and analysed. In general, constructivism maintains that knowledge is built or constructed within the learner's mind by the learner. Thus, learning is an active process. Learners acquire knowledge and use it to draw their own conclusions and develop their own beliefs. As the learner gains more information, it is added to and mixed with previous information and beliefs (Grandy 1997).

These ideas are really nothing new. The belief that knowledge is constructed within the mind of the learner has been around since the time of Socrates (Nola 1997). What is new is how constructivism is being implemented in the classrooms, the implications for research investigations, and the diversity of types of constructivism that currently exist.

Within the all-encompassing classification of constructivism there exist several different types, including radical constructivism, with its roots from von Glasersfeld; personal constructivism, from the work of Kelly and Piaget; social constructivism, based on the work of Solomon; social constructionism, from Gergen; critical constructivism, proposed by Taylor; and contextual constructivism, developed by Cobern (Geelan 1997). All of these believe that knowledge is actively constructed. However, where the knowledge came from—whether it was personally or socially constructed—is at the heart of the difference between the types (Geelan 1997). For the purpose of this research, the focus shall be on students personally constructing their own knowledge, with the help of the teacher. This is in line with the work of Driver, Piaget and others, which can be

called a 'personal-objectivist' type of constructivism (Geelan 1997). Because this research is more concerned with teaching chemistry and how students make sense of that teaching, rather than with epistemology (Geelan 1997), this type of constructivism forms the basis for analysis and implications in this study.

Background

While other methods for identifying students' misconceptions and understandings exist (Winer and Vazquez-Abad 1995), several studies have established the validity and utility of concept maps as an evaluation tool (Pendley *et al*. 1990, Shavelson *et al*. 1993, Markham and Jones 1994, Nakhleh 1994). For instance, Markham and Jones' study (1994) used concept maps to evaluate the differences between biology majors and non-biology majors. In so doing, they established the validity of the method for comparing the links of students based on their concept maps. The extensive literature reported by Shavelson *et al*. (1993) cites multiple examples of how concept maps have been used in the sciences in general and in chemistry in particular. In addition, it also outlines multiple ways of scoring and using concept maps as assessment tools. Of particular note to the chemistry field is the use of concept maps by Pendley *et al*. (1994), who established that concept maps could be used in chemistry to help students facilitate their understanding of chemistry. Finally, the work of Nakhleh (1994) was an important and relevant contribution to the field of concept mapping in chemistry, as she outlined a means of using concept maps generated from an open ended interview to evaluate students' understandings of acid/base chemistry. This is particularly useful to this research, which also employs concept maps generated from student interviews.

Concept mapping has been hailed as a powerful tool for students to organize their own conceptual understanding of domains (Regis *et al*. 1996). Although originally introduced to help students organize their understanding of topics with a hierarchical nature, the method is also useful for topics that are highly interconnected. Thus, concept mapping has been adopted as a useful tool for beginning chemistry students as a way of organizing the material in the teaching of the course (Erduran 1996). Concept maps were originally designed to help both teacher and students organize their own understanding of a subject, but they have been used in a variety of disciplines, employing different strategies and evaluation schemes (Malone and Dekkers 1984, Vargas and Alvarez 1992, Rye and Rubba 1996). Rye and Rubba (1996), for instance, compared an interview protocol that did and did not use concept maps to elicit students' understandings of environmental problems. Vargas and Alvarez (1992) presented a technique for grading concept maps as an alternative assessment method in science classes. Finally, Malone and Dekkers (1984) presented concept maps as an alternative form of assessment for primary school teachers to use during science instruction.

While concept maps are a qualitative representation of students' conceptual understanding, researchers have attempted to use a variety of scoring techniques on concept maps to be able to quantitate the trends among concept maps. There exists a wide variety of ways to generate and subsequently grade or assess concept maps (Stewart 1980, Moreira 1985, Raven 1985, Stuart 1985, Shavelson *et al*. 1993, Liu 1994). Liu (1994), for instance, proposed using item response theory, which takes into account the number of links, the number of hierarchies, the number of cross-links, and the number of examples when scoring concept maps.

Similarly, Moreira (1985) presented a method specifically designed to assess concept maps generated to represent students' understandings of hierarchical physics concepts. Raven (1985) took a slightly different approach to scoring, employing differentiation (number of categories employed), discrimination (range of phenomena involved), and integration (efficiency of organizing method) as the criteria for scoring. Stewart (1980) employed information processing theory to evaluate concept maps generated from student interviews. Finally, Stuart (1985) argued for scoring concept maps holistically instead of numerically.

In fact, Shavelson *et al*. (1993) has identified not less than 128 possible ways of generating and scoring concept maps! Of particular interest for this research is the non-hierarchical concept map, or network concept map, which, according to Shavelson (1993) and others (White 1987, White and Gunstone 1992), is perfectly justified for material that does not necessarily have an obvious hierarchical nature. The network concept map has grown out of work on the associationist theory, which simply interrelates concepts instead of attempting to rank them (Shavelson *et al*. 1993).

This is important for this study since, unlike biology, chemistry is not necessarily hierarchical (Novak 1990, Zoller 1990). While biology is a very organized discipline with structure and subcategories (Novak 1981), chemistry is more of an interconnected web of topics of equal importance (Novak 1990). This point may well be argued (Zoller 1990), depending on how each individual conceives the information. However, what we are trying to capture in this study is how students organize the information and students' individual concept maps may not be organized in a hierarchical manner.

In light of the previous research that has been done using concept maps, this paper reports a novel means for evaluating the intricacy of highly complex, non-hierarchical concept maps. The previously discussed papers detailed methods for assessment of hierarchical maps or maps with a fixed number of nodes. In contrast, the method reported here is specifically suited to large, interconnected, complex and non-hierarchical concept maps. The method focuses on the contextual information in the concept maps—the links—and involves a three-tier analysis scheme to represent the utility, stability and complexity of students' links. For this study, the concept maps were generated from interview transcripts. The analysis scheme is illustrated below with examples from a study of 56 college undergraduates to determine students' understandings of the concepts of bonding, electronegativity, electrons and geometry. The results of the actual study are reported elsewhere (Nicoll *et al*., in pess).

Procedure

The concept map analysis procedure was developed within the context of a larger study that sought to evaluate how students linked together the chemical concepts of bonding, electronegativity, electrons, and geometry. Students participated in individual, hour long, semi-structured interviews. The interview protocol was refined during a pilot study of 20 students and was actually conducted on 56 undergraduate chemistry majors. The participants were volunteers from six courses: general chemistry for science and engineering majors, general chemistry for chemistry majors, organic chemistry, inorganic chemistry, and physical chemistry. Twenty volunteers were interviewed from the general chemistry sequence

for science and engineering majors, while six were from physical chemistry. There were ten participants from each of the other courses. These interviews, which were audio-taped with the consent of the students, were transcribed and concept maps were generated using a set of rules. This paper will not focus on a discussion of the interview data, but on the technique for the analysis of the concept maps themselves.

Analysis procedure

Inter-rater agreement

The conventions for drawing and coding the concept maps were developed and refined during a pilot study containing 20 students and used during the actual study, which contained 56 students. After the interviews were completed, concept maps were generated for each interview and coded by three analysers.

The concept maps were analysed with the transcripts of the interview in hand, so that the 'flavour' of the links could be captured in the three-tier system. For example, once the skeleton of the concept map had been generated, the transcripts were re-read with the concept map in hand and the utility, stability, and complexity of each link was assigned, using analysis rules outlined below.

The analysis rules presented in table 1 were also evaluated and approved by a panel of eight chemical education experts, comprised of professors and graduate students. To establish the inter-rater agreement of the analysis scheme, three analysers independently used the conventions outlined in table 1 to draw concept maps for a random set of five interviews. The agreement between the three analysers was determined by comparing how two of the analysers had assigned the utility, stability, and level of utility of each link compared to the third analyser.

The three analysers were chosen in order to establish the reproducibility of the coding scheme. While all were chemical education specialists, one was the primary investigator of this study. Of the other two, one of the analysers had already been trained on the coding protocol from the pilot study, while the other was simply given the coding rules for generating concept maps and asked to draw the maps from the interview transcripts. This was done for several reasons. First of all, the original analyser from the pilot study was used to ensure good inter-rater agreement. The third analyser was intentionally not trained as the second analyser had been, however, to determine if others not specifically trained on how to draw the concept maps could achieve a similar level of inter-rater agreement.

Nodes were counted as similar if the same word or phrase was used. For example, 'Carbon dioxide' and 'CO_2' were counted as similar nodes. The phrases connecting nodes were counted as similar if the 'flavour' and directionality of the proposition were the same. For example, 'Electrons $\xrightarrow{\text{are in}}$ Bonds' and 'Electrons $\xrightarrow{\text{make up}}$ Bonds' were counted as similar. The inter-rater agreement was determined to be 0.74 overall. This value was deemed acceptable for this study considering the complexity of the concept maps involved (Shavelson *et al*. 1993).

Decision rules

The following decision rules were developed for use in this research study. First, for the purposes of this research, links had to be self-contained between two nodes. In other words, this work excluded dependent propositions. This was done to

Table 1. The three-tier coding rules used in this study to evaluate students' links in concept maps.

Link Coding

1. Utility
   1.a. Useful: ⟶
   - Links are 'correct' in the textbook sense
     Example: Orbitals → have different → Shape
   - Includes links to non-traditional, but generally sound examples
     Example: Hybrid → like → Corn
   1.b. Wrong: ⟹
   - Links contain wrong information
     Example: Electromagnetic force → is → Dipolar
   - Includes links to incorrect examples
     Example: Electron → like → Planets
   1.c. *Incomplete:* ⟹
   - Links aren't totally complete: they may be correct as far as they go, but more information is necessary to make the link useful or wrong
     Examples: Atoms → gain and lose → Electrons
     Nucleus → has a → Positive charge

2. Stability
   2.a. Defined: <u>*Solid line*</u>
   - Links are well defined and solid.
   - Students may repeat the information several times through the course of the interview.
   - Students are 'sure' of the information.
   2.b. Emerging: Dashed line
   - Students appear to have tentative links to the information.
   - Students state that they're 'not sure', or 'think so', or 'guess'.
   - Links are vague, such as: 'has to do with', or 'relates to'.

3. Levels of Utility
   3.a. Used for links coded as 'useful' only
   3.b. Level #1: Examples
      3.b.i. Linked with 'like', 'can be', 'looks like', 'is an example of' or 'is'
         Example: Hybrid $\xrightarrow{is\ like}$ Corn
   3.c. Level #2: Fundamental Fact
      3.c.i. Can be found as a simple, basic fact in a textbook
      3.c.ii. Evidence of wrote memorization in concept map.
      3.c.iii. Students can't or don't explain 'why?'
      3.c.iv. Students state that they just 'know it's so'.
      3.c.v. Doesn't contain 'like', or an implied causation in the link.
         Example: Orbitals $\xrightarrow{hold}$ Electrons
   3.d. Level #3: Explained by other links
      3.d.i. Links are complex and/or have predictive power
      3.d.ii. The explanation or justification for the link can be traced back through the concept map.
      3.d.iii. Usually linked with causation type words, like 'affects', 'causes', 'because of', or 'has a trend in'
         Example: Lone pair $\xrightarrow{affects}$ Geometry

simplify the concept maps as much as possible. Because students' maps were generated from the interview transcripts, the maps included all the concepts that students mentioned, which grew to be quite large and complex. Although some studies have allowed 'sentences' through multiple nodes (Shavelson *et al*. 1993), this study did not employ this technique in an attempt to simplify the concept maps, as the number of links and nodes already present made the concept maps very complex.

Secondly, different types of arrows could be used to represent students' links, or propositions, and how they thought about the material. Specifically, a student's link could be 'one-way': the student could only think about the material in one direction. In this case, the link was represented by a line with one arrowhead, indicating the direction that the student used the link. If the interview transcript showed evidence, however, that the student could use the link in both directions, that the student had a 'two-way' link, then a double arrowhead was used in the concept map between the two nodes (Fisher 1990). The text above the link represented a double link by using the words the student used for each direction of the link, separated by a slash. For example, if a student constantly stated throughout the interview that 'Electrons orbit the nucleus', then the link would be a one-way link: Electrons $\xrightarrow{\text{orbit the}}$ Nucleus. However, if the student also mentioned through the course of the interview that 'the nucleus attracts electrons', then this would constitute a two-way link: Electrons $\xleftrightarrow{\text{orbit the/attracts}}$ Nucleus.

Analysis rules

After the nodes and propositions for the concept maps had been drawn, a method of assessing the utility of the links was necessary, since this study focused on a comparison of the links between students. Initially in the pilot study, the degree of cross-linking of each map was assessed. However, this proved to be very difficult for these concept maps. An assessment of cross-linking is traditionally done for hierarchical concept maps (Shavelson *et al*. 1993). The concept maps in this study, in contrast, were generated from student interviews and represented how students linked the material together, which was not necessarily hierarchical. Therefore, another more appropriate means of assessing the linkages was necessary for this study. As a result, the advanced, three-tier coding scheme of the links was developed by the primary investigator in the pilot study and used in the actual study (see table 1).

The categories described below were developed from the data. After the concept maps had been generated, some pervading themes came out of the transcripts. It was not sufficient to analyse the links for scientific correctness. Instead, it was noted that some links were more useful than others. A means of representing the different shades of link complexity was necessary. It was also observed that there were some links that students were more certain of than others, and a method of representing this in the concept maps was warranted to reflect how 'sure' students were of their knowledge.

First level of analysis: utility

Each link was first evaluated to determine its utility. The utility was classified into one of three categories: namely if it was incorrect, incomplete, or useful. An

incorrect link is one in which the information stated by the student does not conform to the accepted, scientific view. For instance, an excerpt from the interview of Alex, a freshman in general chemistry, went as follows:

    I: Okay, could you please explain what holds two atoms in a molecule together?
    S: The attraction between electrons.

From this, the link 'Electrons $\xrightarrow{\text{are attracted to}}$ Electrons' was generated, as seen in figure 1, which was then marked as incorrect, which is represented with a thicker line. The scientifically accepted link would have been that electrons repel other electrons.

In contrast, the utility of the link was interpreted as incomplete if the information that the student mentioned was correct as far as it went, but was missing some key point in order to be counted as correct according to the accepted definition of the chemical community. Looking again at Alex's transcript, when he was asked to define what the term 'polar' meant, he stated,

    I: Ah, you mentioned a couple of terms there—covalent and non-polar. Could you please explain what those are?
    S: Yeah ... polar is, is the, ah, sharing of electrons.

From this excerpt, the link 'Polar $\xrightarrow{\text{is the sharing of}}$ Electrons' was generated, as seen in Figure 1, which is represented with the thickest line. While it is true that polar bonds consist of shared electrons, the key point is that it is an uneven sharing of electrons. However, Alex never stated this point. Thus, the link was coded as incomplete.

The utility of the link was interpreted as useful if the link was correct and allowed students to correctly solve chemical problems. Useful links comprised the balance of the links that students had and are coded with a thin line. These were typically scientifically sound concepts and links, like 'Electrons $\xrightarrow{\text{are in}}$ Orbitals', although some were more non-traditional links, such as 'Hybrid $\xrightarrow{\text{is like}}$ Corn'. In the first example, the student was demonstrating his knowledge of basic chemistry facts. In the second, the student has made an analogy between the hybridization in molecules and in corn. While this is not a traditionally accepted means of thinking about hybridization between chemists, it was a useful analogy for this student. Therefore, it was coded in the useful category.

Second level of analysis: stability

After the links were coded for utility they were coded for stability, which represented how confident students were of the information they were saying. The stability of a link was represented by two categories: defined and emerging. Links were classified as defined if students indicated that they firmly believed what they were saying to be the case. When students overtly expressed confidence in the information, the link was classified as a defined link. Alternatively, students might have stated the link multiple times during their interviews. Students may also have stated the link firmly in a declarative sentence, indicating that they were sure of the information. For example, during Alex's interview, he likened orbitals to rings going around the nucleus: ' ... electron orbitals are ... like rings going around the nucleus. And electrons are on those rings going around constantly'. Here, Alex has stated the information matter-of-factly and did not state that he

was unsure of himself, so the links 'Electrons $\xrightarrow{\text{are on}}$ Rings' and 'Rings $\xrightarrow{\text{go around}}$ Nucleus' were analysed as defined links, as seen in figure 1 and designated with solid lines.

In contrast, links were classified as emerging if students said that they weren't sure about the information. Note that students were told at the beginning of the interview that it was all right to say if they weren't sure about any information. In such situations, students usually said, 'I'm not sure about this, but . . . ', 'I think this is so . . . ', or some other cue which indicated that they were not sure about the information. While Alex (figure 1) did not have any links that were classified as emerging, an excerpt from Bill's interview illustrates an example of an emerging link. Bill, a senior in physical chemistry, was explaining what covalent bonds are: 'Ah, carbon and hydrogen, most all organics are covalent. I mean, I guess it's, well, yeah, I'm not sure about that'. From this quote, the link 'Organics $\xrightarrow{\text{are}}$ Covalent' was first generated. The link was then evaluated as emerging and designated with a dashed line, since Bill stated that he wasn't sure about this connection.

Third level of analysis: complexity

A means of analysing the complexity of the maps, independent of the number of links, was necessary. Since cross linking wasn't an appropriate measure of these non-heirarchical maps, this three-tiered system was devised to more easily represent the complexity of the maps. The useful links were assigned a number to indicate their Level of Utility, where 1 indicated an example, 2 indicated a fundamental fact, and 3 indicated a link that was explained by other links. For a detailed list of the analysis rules used to assign the Level of Utility, see table 1.

It is important to note that links may be coded as either useful, incomplete or incorrect as well as defined or emerging. Those links that were coded as useful—either emerging or defined—were subjected to another level of analysis. The purpose of this third tier of analysis was to reflect the level of complexity of the concept maps in a meaningful way. It was evident upon generating the concept maps that some links were more useful than others and a means was needed to reflect this difference. For instance, in Alex's concept map (see figure 1), the link 'Angle $\xrightarrow{\text{can be}}$ 109"' is not nearly as useful for predicting phenomenon in chemistry as is the link 'Bond $\xrightarrow{\text{is different because of}}$ Electronegativity'. The first link is a simple example, which cannot be used to solve complex chemical problems. The second link, in contrast, is a link that can be used to explain why there are different types of bonding and how electronegativity affects these types of bonding. While these are both correct links, there is a large difference in their predictive ability. Thus, a student may have a large map with many simplistic links with little predictive ability, while another student may have a smaller map with more useful, predictive links. Because of this, it was not a useful measure of comparison to simply count the number of links that each student had and make generalizations based on the total number of links.

Use of levels in analysing data

Level 1 included all those links to simple examples that students had, such as 'Water $\xrightarrow{\text{is}}$ Polar' or 'Noble Gas $\xrightarrow{\text{has 8}}$ Electrons'. It also included all those links on the concept map which were connected by 'can be', such as 'Bond $\xrightarrow{\text{can be}}$ Double'.

Level 2 included those links which were fundamental facts, such as 'Electrons $\xrightarrow{\text{move in}}$ Orbitals'. Level 2 links may show evidence of rote memorization from the textbook, or students may outright state, when probed to explain why, that they just know it's so from the textbook. Level 3 links, on the other hand, are links that can be explained by other links in the concept map. These links have significantly more predictive power and utility than the other levels in the analysis scheme because students could potentially use these links to explain and predict chemical phenomena. They were different from level 1 or level 2 links, which required only rote memorization. These links usually have linking words that imply causality, such as 'affects' or 'because of'. For instance, 'Lone Pair $\xrightarrow{\text{affects}}$ Geometry' is coded as a level 3 link. To represent the Level on the concept map, small boxes were placed to the side of each link with the number of the Level inside.

Finally, each concept map was colour coded to allow for easy assessment of the maps (see figure 1). The maps were assessed for the total number of useful, incorrect, incomplete, emerging and defined links. The number of level 1, 2, and 3 links was also counted. The concept maps could then be compared and analysed between students and between groups. For instance, a statistical comparison of the number of correct, incorrect, incomplete, emerging and defined links could be performed on the data from the concept maps. A similar analysis could be done to compare level 1, level 2 and level 3 links as a function of educational level. These types of analyses serve as a useful tool in comparing data obtained using concept maps.

Conclusion

The analysis scheme outlined above was successfully applied to a sample of 56 concept maps representing undergraduates' links between chemistry concepts. The method has been useful for representing the complexity of students' links in intricate concept maps with a non-hierarchical nature. The method, however, could as easily be applied to hierarchical maps to represent the complexity of students' links in any discipline.

A novel means of coding and assessing concept maps based on the utility, the stability, and the complexity of the links has been established. The method is unique from other methods for analysing concept maps that have been previously reported in that the coding scheme does not rely on the hierarchical nature of the map, the map's organization, or the differentiation, discrimination, and integration of the concept map. Instead, this method takes a novel approach by focusing on the propositional knowledge contained in the links, the stability of students' knowledge, and the level of complexity of the links. This yields more information about students' knowledge structures and how they learn information.

This analysis scheme may be useful from a teacher's standpoint, as it allows an alternative method for assessing concept maps generated by students. It also affords teachers a new tool with which to 'peer' into students' minds and ascertain what and how students are learning. By coding the links as emerging or defined, stable or not, and complex or not, teachers can obtain useful information about how students are understanding the knowledge presented to them. This can be used as an assessment technique to gauge how well students are assimilating the new information.

From a researcher standpoint, this analysis technique is a new tool for determining how students learn and how they represent their own knowledge. While other assessment techniques are available for concept maps, this one presents a different view of how students integrate knowledge—both old and new—in their concept maps. The three-tier system allows for assessment of three different properties: stability, utility, and complexity, which have not been assessed before in other schemes.

This type of analysis may be particularly useful for future investigations of how students organize information and how they add new information onto existing information. Indeed, future research may focus on the implications of this analysis scheme, including representing how students learn chemistry, how students integrate new knowledge into their existing structures, and how best to introduce new knowledge to students. This scheme may open doors to new ways of representing students' knowledge processes, not only in chemistry, but in other domains as well.

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