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A DEVELOPMENTAL FRAMEWORK FOR ASSESSING CONCEPT MAPS

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Abstract: This paper describes the application of a developmental assessment model to the analysis of concept maps prepared by students in upper primary, mid-secondary and senior years of schooling. The model, referred to as SOLO (Structure of the Observed Learning Outcome), provides a means for interpreting student responses within a framework of cognitive growth. A key feature of the model is its focus on the quality of a student response. Based on a discussion of key features of students' concept maps, descriptors are proposed from a SOLO perspective for increasingly complex concept maps.

1 Introduction

The qualitative analysis of concept maps has focused on detailed descriptions of map features. Such descriptions have documented similarities and differences in the way groups of students manipulate concepts (Williams, 1995), the extent to which maps exhibit progressive differentiation (Henderson, Patching, & Putt, 1994; Starr & Krajcik, 1990) and when changes take place in student's conceptual understanding over time (Fellows, 1993). In addition to the misconceptions and inconsistencies which concept maps reveal, they can also be analyzed for the gaps that are apparent in students' knowledge. Such gaps may not only be representative of missing concepts, they may also suggest that conceptual relationships have not yet been made between items in a student's cognitive structure. Fellows (1993) used a number of criteria to analyze concept map changes over time. These criteria included the incorporation of new concepts, the addition of domains of knowledge, the hierarchical organization of concepts, and the identification of strongly held beliefs. There have also been suggestions that analysing the diversity and richness of concept maps would benefit from a " ... holistic and qualitative technique" (Stuart, 1985) or that "as students develop increasingly sophisticated scientific knowledge, it might be useful to distinguish their statements via a more elaborate hierarchy of accuracy ... " (Stoddart, Abrams, Gasper, & Canaday, 2000). The guiding question for this paper is whether or not descriptors for distinctly different groups of concept maps can be developed from the perspective of a cognitive structural model that places student responses within cycles of growth of increasing complexity. Such a focus has the potential to supplement investigations that have focused on the structural changes that can be observed in concept maps over time.

2 The SOLO Model

The SOLO model is a post-Piagetian analytical tool that has the potential to distinguish qualitatively different levels of response to a task along a developmental continuum. The SOLO classification scheme refers to the Structure of the Observed Learning Outcome (Biggs & Collis, 1982). Coding a response – rather than a student, according to the SOLO model requires a consideration, firstly, of the nature of the elements that are used and the complexity of the operations that can be applied to those elements. Such a consideration gives rise, firstly, to *modes* of thinking that are related to the abstractness of thinking. There are five main modes of cognitive functioning within the SOLO model and these are currently referred to as (1) sensorimotor – acquiring motor skills; (2) ikonic – thinking intuitively; (3) concrete symbolic – representing concepts using different symbol systems; (4) formal; and (5) post-formal – manipulating theoretical constructs. Secondly, as an individual becomes more and more familiar with the elements and operations within a mode, a pattern of response structure becomes apparent according to the ease with which students process cues, something which may be related to working memory.

In general, most primary and secondary school students interpret phenomena or undertake tasks within the concrete symbolic mode. This mode is the prime focus for the compulsory school years. As a consequence, during these school years, concrete symbolic is referred to as the target mode (Biggs & Collis, 1989). The goal in any target mode is to raise the level of functioning to the point where responses can be made at a level of sophistication that indicates that the quality of learning which has taken place is adequate or that a skill has been practised sufficiently (Collis & Biggs, 1991). A consideration of increasing complexity gives rise to the second feature of the model, namely *levels* of responses. There are five main levels of responding within the model: *Prestructural* (P) – no use of elements which belong to the mode in question; *Unistructural* (U) – identification of one relevant element of the required mode; *Multistructural* (M) – thinking about two or more pieces of information relevant to the target mode; *Relational* (R) – the relationships between separate pieces of information have been considered to produce an integrated understanding; *Extended Abstract* (EA) – a transition to a new mode of thinking through the use of material which is new or of increased abstraction.

Of the five SOLO levels, three constitute a learning cycle within a particular mode, namely, unistructural, multistructural and relational, whilst the other two, pre-structural and extended abstract, lie outside this mode (Biggs & Collis, 1982, 1989). Entry into a mode is determined by a unistructural response in that mode of functioning or by moving beyond the relational level in a previous mode. Transcending the relational level implies the ability to formulate an extended abstract response and the overlap between an extended abstract response in one mode and a unistructural response in the next mode is explained as "the extended abstract response in one mode jumps the barrier to form the unistructural response for the next higher mode" (Biggs & Collis, 1982, p.218). The model proposed (Biggs & Collis, 1991) brings together successively the cyclical nature of learning (levels) and the hierarchical nature of cognitive development (modes). Inherent in the learning cycle is a sequence from low competence (novice learner) to expertise (Biggs & Collis, 1989) with each level being an indicator of how far learning has progressed towards competence. The sequential progression through the learning cycle, with progression towards modes of higher abstraction in an 'onwards and ever upwards' process has been termed the course of optimal (cognitive) development (Biggs & Collis, 1989). In later developments of the SOLO model, the notion of the course of optimal development has undergone refinements to incorporate linear development within a mode and development across modes (Collis, 1988; Biggs & Collis, 1989). The terms 'unimodal' and 'multimodal' are introduced to explain expertise and intelligent behaviour (Biggs & Collis, 1991). In addition, the notion of the U-M-R learning cycle has been refined to incorporate multiple cycles within a mode (e.g., Collis, Jones, Watson, Sprod & Fraser, 1998; Panizzon, 1997; Pegg, 2003).

3 Data – 'Matter' Concept Maps

Ten maps are briefly discussed in terms of the holistic arrangement of concepts and the meaning developed based on proposition grouping and the linking of concepts. The maps were prepared collaboratively by students in groups of 3-4 from Year 4/5 (upper primary), Year 9 (middle secondary) and Year 11 (senior secondary) using 20 words about 'matter'. The students were from an all girls' boarding school in a regional location. They were not experienced in concept mapping and a series of four 1-hour structured sessions provided them with practice in acquiring the necessary techniques. Throughout the discussion that follows, reference is made to 'themes' in an 'expert' concept map. The 'expert' was a post-graduate student with a background in the physical sciences and some familiarity with concept mapping. The 'themes' refer to the way concepts were grouped using the same words provided to the students and they were identified as: the classification of matter; changes of state; kinetic-molecular behaviour of particles; an atomic description of matter.

Map 1: The way each of the concepts is placed separately around the main concept in Figure 1 provides an example of a structurally *Discrete* map – one of six visual descriptions of maps. Single words have been selected from each of the four 'expert' map themes, however, these themes are not developed.

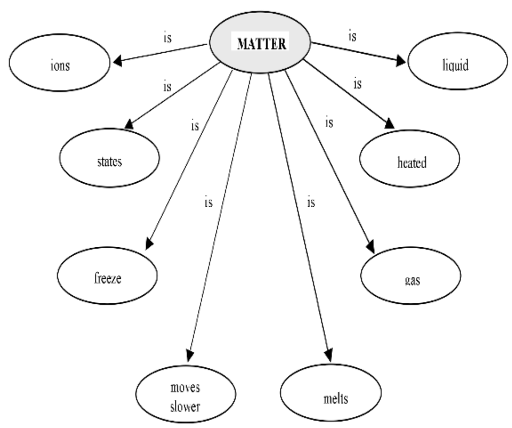


Figure 1 Concept Map of 'Matter' for Group Yr4/5 B1

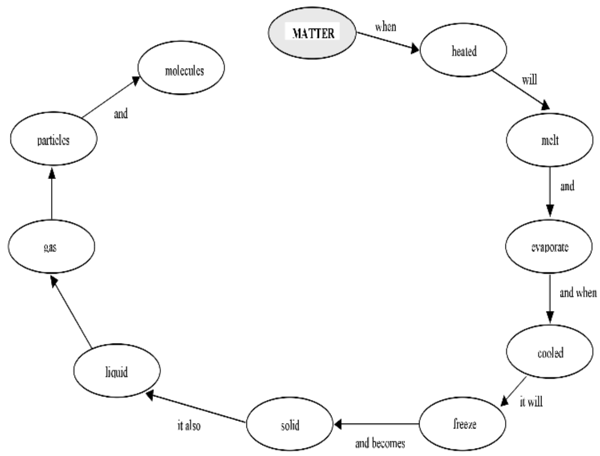


Figure 2 Concept Map of 'Matter' for Group Yr4/5 A2

The main feature of this map is the presentation of discrete pieces of information, ordered as single propositions incorporating the same link term throughout. The construction of a generalizable proposition (one that is part of an agreed shared language within a discipline, such as science) is almost coincidental, suggesting that students have focused more on the correct appearance of a proposition than on the propositions themselves. In SOLO terms, this suggests an Ikonic mode of thinking.

Map2: This is an example of a *Single Strand* map (Figure 2) and it incorporates three of the themes identified in the 'expert' map. The main focus is on changes of state and the six concepts which begin this strand are used to list propositions about the behaviour of matter when it is heated or cooled, i.e., it will melt, evaporate, and freeze. Although there is a break in the 'flow' of ideas after the concept 'solid,' the listing of attributes of matter is maintained, with four additional concepts added as labels for matter. These concepts concern the classification and the atomic nature of matter, and it is of interest that the students who prepared this map have extended one strand rather than begin the process of constructing another strand based on a different theme. In SOLO terms this map is consistent with a multistructural level of treating concepts.

Map 3: This is an example of a *Multiple Strand – linear* map (Figure 3). Based on 9 of the 20 terms provided, one strand describes changes of state whilst the second strand makes reference to an atomic view of matter. The separation of this information into two thematic strands suggests that students may have made decisions about the underlying meaning of each strand. Whilst students may have been able to use the map structure to distinguish between different themes, the main feature of this map is the sequential presentation of information. One theme is stated and then students have begun again to present new information. In SOLO terms, such a treatment is consistent with a multistructural level.

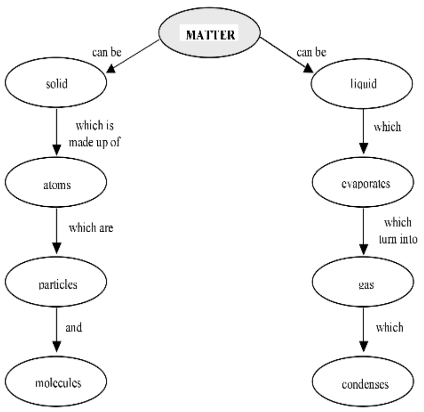


Figure 3 Concept Map of 'Matter' for Group Yr4/5 C2

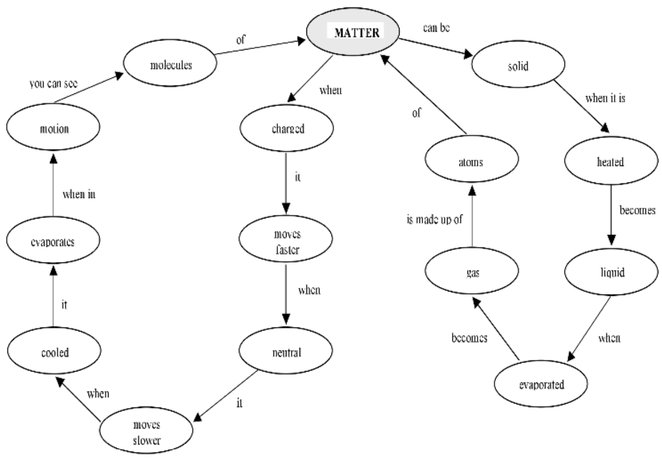


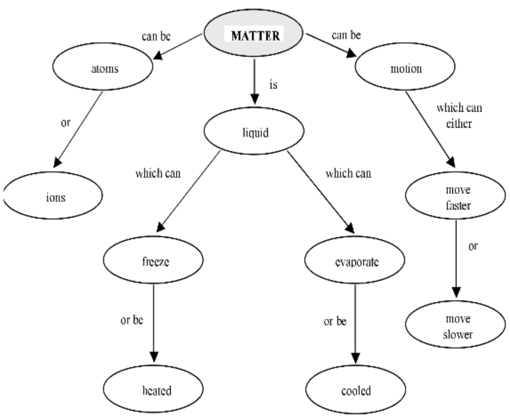
Figure 4 Concept Map of 'Matter' for Group Yr4/5 B1

In the right hand strand, students indicated that they could recognize changes of state that involve heating and cooling, applying this to liquids and gases, respectively. Even though 'solid' was included in the map, it has not been incorporated into the changes of state theme. There are two possible explanations for the absence of this link. One is that students cannot use a concept in multiple contexts: students may not have recognized that 'solid' has a meaning within a changes of state theme *and* an atomic view of matter theme. Secondly, the physical (visual) separation of a concept has possibly prevented students identifying a conceptual link. As with Map 1, the complexity of this map may be related to the number of elements that students can consider concurrently, namely, creating propositions and using the structural components of a concept map.

Map 4: The arrangement of concepts in this map (Figure 4) provides another example of a *Multiple Strand – linear* map with words grouped according to all four 'expert' map themes. The sequencing of these words, however, is different from the previous example. Here, they take the form of separate groups of propositions. The 'flow' of the left hand strand of this map is not continuous as it can be written out as four statements, each of which is about a different aspect of matter. This strand does not therefore convey understanding about a single theme. Rather, it represents the listing of different aspects of matter. The first of the statements uses the concept 'charged' in an everyday context, as has 'neutral' in the next proposition. The next statement, on initial inspection, indicates a faulty proposition. This reference to evaporation, however, could represent the recollection of observations made about the appearance of frozen objects when removed from a freezer. As a consequence, the underlying meaning of this statement is not immediately apparent and it imparts a context-specific nature or personally relevant meaning to the strand.

The second strand in this map can also be written as a number of separate statements, the main focus of which is changes of state. This theme is conveyed using six concepts in a continuous way and there is no need to repeat the main concept in order to make a proposition meaningful. After this sequence of propositions, a different theme is introduced, that of atoms. The meaning conveyed by both groups of propositions is generalizable. In SOLO terms, the way students have been able to maintain the 'flow' of concepts is consistent with a relational level of thinking. This map reflects another aspect of applying the model, namely that a level is assigned to a response on the basis of its most complex feature. This map reflects both individual and scientific perspectives, with the later taken as the more complex.

Map 5: This is an example of a *Multiple Strand - branched* map (Figure 5), a structure that has been used to group concepts related to each of the four 'expert' map themes. In common with the previous example, the strands are short and a separate one is used for each theme.



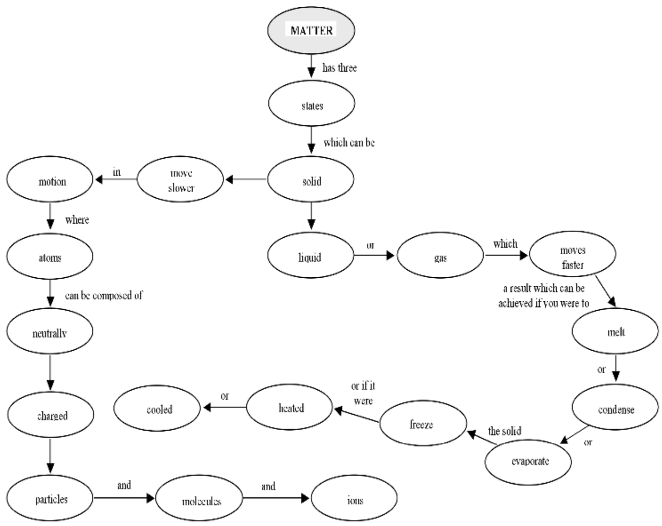


Figure 5 Concept Map of 'Matter' for Group Yr4/5 E2

Figure 6 Concept Map of 'Matter' for Group Yr9 A2

The first linear strand makes a generalizable statement about the atomic description of matter based on the recall of discrete pieces of information. The other linear strand refers to the behaviour of matter with some indication that it is based more on everyday observations than on abstract concepts. The focus on either particles or motion is consistent with a unistructural level of thinking. The main point of interest in this map is the way in which concepts relating to states and changes of state have been treated. One state has been selected and this has become a branching point for a discussion of changes of state. In this sense, the strands comprise two themes, however, they have been linked without any interruption to the 'flow' of meaning. The focus of these strands is that a liquid can undergo two changes, one associated with heating and the other with cooling. It is interesting to note that the terms 'heated' and 'cooled' are associated with terms of opposite meaning, e.g., " ... liquid which can freeze or be heated." Such a sequence indicates an understanding of the two-way processes that apply to a liquid and this conveys a preliminary awareness of the notion of reversible processes. The main feature of this map is the use of strands to link propositions in two qualitatively different ways that can be explained in terms of qualification. The first relates to the use of a link word, such as "or", that leads to the construction of a strand in which information is itemized, i.e., without qualification. The second relates to links, such as "which can", that allow for propositions to be qualified. The qualified propositions can convey a more detailed understanding of concepts. Such qualification of one concept is consistent with unistructural thinking at a complex level.

Map 6: This is an example of a *Single Strand – branched* map (Figure 6), even though the major part of this map comprises two strands. All the terms provided were used in the map and, consequently, the potential exists for all four themes of the 'expert' map to be discussed. With only two strands, however, there are implications for how students treat the 'flow' of ideas along these strands. The first theme to be stated is that of classification into states and a branching point introduces the idea of the motion of particles. The motion theme becomes the cue, and provides a transition to a discussion about matter from the atomic viewpoint. The ideas about motion and the atomic view of matter are not integrated and this lack of integration generates a break in the 'flow' of meaning. In the right hand strand, the motion theme again provides a transition to ideas about changes of state. With the terms 'moves faster' and 'melt', students have attempted to make a causal connection between motion and the processes associated with changes of state. The intent to maintain ‘flow’ along this strand is reinforced through the repetition of the term ‘solid’ later in the strand. The lengthy strand structure, however, has not resulted in a clear enough distinction between terms associated with changes of state and, consequently, the integration of ideas about heating and cooling contained in this strand does not have continuous ‘flow’. This confusion might have been resolved with the inclusion of a branching point, however, students appeared unable to incorporate this feature into their thinking about matter. A key feature of this map is that the separate strands are representative of the sequencing of a number of themes with breaks in the ‘flow’ of meaning. In SOLO terms, these breaks in the ‘flow’ reflect a multistructural level of thinking. Overall, however, this map is consistent with unistructural thinking at a complex level in the way one aspect (e.g., motion) of a theme (e.g., changes of state) is developed.

Map 7: This is an example of a *Multiple Strand - branched* map (Figure 7) which uses terms associated with each of the four ‘expert’ map themes. The two outer strands focus on states and changes of state and the two inner strands focus on kinetic-molecular and atomic aspects of matter. The two strands which outline changes of state detail the macroscopic, observable, features of this change. The shorter of the two strands comprises a simple, generalizable, statement that matter “melts then evaporates,” processes which require heat. In contrast, the second strand specifies each state and the processes which form the sequence of the cooling of a gas, even though heat is not explicitly mentioned. Considered together, these two strands convey the notion of reversibility, although the absence of links between them in this map results in this idea remaining implicit.

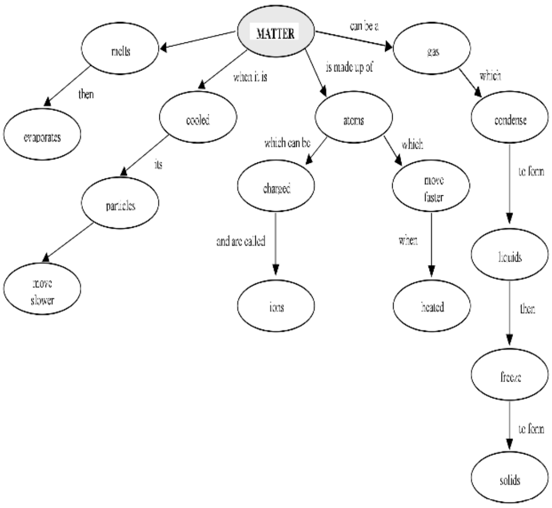


Figure 7 Concept Map of ‘Matter’ for Group Yr9 B2

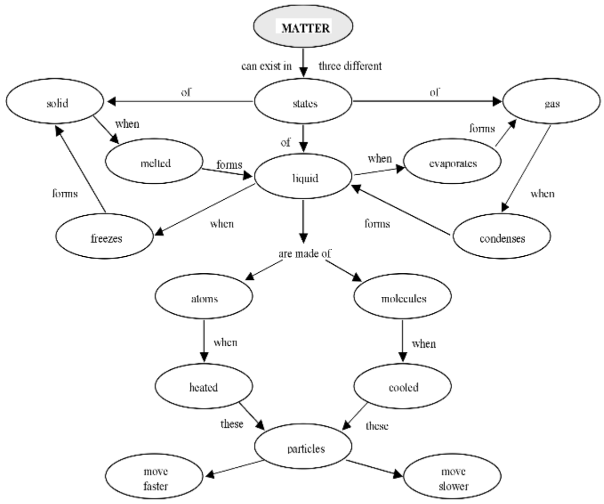


Figure 8 Concept Map of ‘Matter’ for Group Yr9 F1

The two central strands follow a similar pattern. The left-hand strand represents a generalizable statement about the behaviour of cooled particles. The second strand also integrates two themes. The way this is achieved, however, is different from the strand about states and changes of state. In this strand, the term ‘atom’ has become a cue for students to discuss two separate ideas about atoms, namely their particle nature and motion. One meaning relates to an atomic view of matter and the other to a kinetic-molecular context. The main feature of this map is the way in which the structural features of maps have been used to integrate themes along a strand. The potential existed within this map for a cross-link to be made, however, this structural feature was not incorporated and this may reflect the limit of students’ processing as they managed the requirements of the task and their understandings. In SOLO terms, the capacity to present a theme (e.g., the motion of particles) and elaborate on one aspect (e.g., the charged nature of particles) is consistent with unistructural thinking at a complex level.

Map 8: This is an example of a *Complex* map (Figure 8), indicating that all of the structural features of maps have been included. In addition, terms have been selected which are associated with the four themes of the ‘expert’ map. In the first section of this map, the concept ‘states’ is used as a branching point to identify the three states of matter. Propositions are then added which, together, give an overview of all of the processes that are associated with changes of state. In addition, these propositions are cross-linked in a way which conveys the notion of reversibility. In the sequence of propositions “a solid when melted forms a liquid when freezes forms a solid,” for example, both the heating and the cooling processes are itemized. This arrangement can be compared with the map in Figure 7 where the ideas are arranged separately. In the second section of the map, the concept ‘solid’ becomes the cue for integrating ideas about the kinetic molecular and particle aspects of matter. The main feature of this map is the use of all mapping structural features to integrate themes in a generalizable way without a loss in the ‘flow’ of meaning. In addition, the notion of reversibility, which is not an explicit part of the words provided, is conveyed through the use of two-way cross-links. The features in this map make it consistent with relational thinking at a complex level.

Map 9: This has been classified as *Multiple Strand - branched* (Figure 9) and all the themes of the ‘expert’ map have been included. Additional words have been added to extend the information about the atomic view and, unlike other maps, a number of the provided words are repeated with most of the repetition occurring in the section about states and changes of state. All of the changes of state are itemized and discussed in terms of the effects of heating and cooling. The underlying structure used to convey this information, however, is a one-directional ‘flow’ along a strand. As has been noted in other examples, the notion of reversibility is implicit and, because students do not appear to have a facility with cross-links, this additional theme remains unstated. The proposition “ ... solid is heated to become liquid ” is the only appearance of a cross-link.

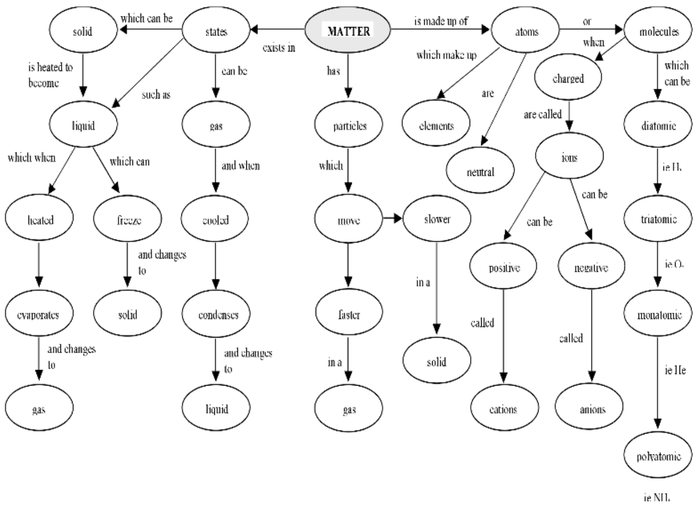


Figure 9 Concept Map of ‘Matter’ for Group Yr11 B1

In the middle section of the map, the motion of particles is considered as a function of their state, an approach that distinguishes this map from others in which the effects of heat were outlined. Finally, the atomic picture of matter is put forward in the last section of this map inclusive of references to the charged nature of atoms and molecules. Although implicit, a distinction between atoms and molecules is made by the inclusion of terms such as ‘diatomic’ and ‘formulae,’ suggesting that students are familiar with the notion of combining atoms. The main features of this map are its extended concept base and the extensive use of strands to itemize information. The elaboration of a number of themes is consistent with multistructural thinking at a complex level.

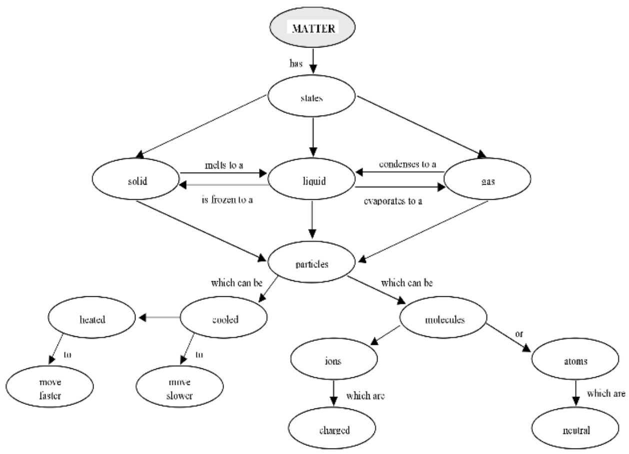


Figure 10 Concept Map of ‘Matter’ for Group Yr11 A1

Map 10: This is an example of a *Complex* map (Figure 10) based on terms associated with each of the four themes of the ‘expert’ map. Both structurally, and in the way ideas are developed, there are similarities between this map and the Year 9 map Yr9F1 (Figure 8). The underlying structure is the use of strands to integrate themes with no interruption to the 'flow' of meaning. In addition, cross-links are used to detail the reversible processes associated with changes of state. Statements are made about the behaviour of particles when heated or cooled, and the concept 'particle' has been used as a focal point for making a distinction between kinetic and atomic aspects of matter. The features in this map make it consistent with relational thinking at a complex level.

4 Concept Maps – A SOLO Perspective

The maps presented in the previous section illustrate some distinctive features of concept maps that can be summarised under three headings. The first relates to the holistic (visual) arrangement of concepts and there was sufficient variation to identify six distinctly different types of maps based on the way structural elements of maps were used. These types were labelled *Discrete*, *Single Strand*, *Single Strand – Branched*, *Multiple Strand*, *Multiple Strand – Branched*, and *Complex*. The second feature of the maps relates to the grouping of propositions. Again, sufficient variation existed to identify maps that ranged from single propositions only through to those that comprised cross-linked strands where the individual strands were made up of sequential 'themes'. For example, the strand was the main structural feature used by Year 4/5 students whilst branching points became an important feature of Year 9 maps, and the inclusion of cross-links characterized Year 11 maps. The third feature of the maps is linked to the way groups of propositions generate meaning. Some key terms used to describe groupings were *itemising* – individual pieces of information listed, *integrating* – links between ideas or themes were identified, *'flow'* – which could be broken or continuous, *personally relevant* – where propositions generated a non-scientific context, and *generalizable* – where the meaning was developed as part of the shared language of the discipline of science. These three features provide a basis for using the SOLO model to formulate descriptions of structural categories for distinctly different maps. These categories are based on the number of elements chosen and how students work with those elements. Applying the descriptors proposed below, most of the maps could be assigned to the Concrete Symbolic mode – the target mode for instruction. Although these examples reflect an age-related progression towards structural complexity, it is important to realise that the structural features of the map are important not who created it. Whilst not all concept maps will necessarily fit a descriptor exactly, each level will have certain essential features that enable a map to be placed within a developmental sequence.

- **Ikonic**: There is a perceptual focus in this mode and there is a sense that students are concentrating on what a concept map should look like (visual correctness) rather than using propositions to create meaning. Propositions are poorly constructed, propositional links may be absent, or a personally relevant context might be conveyed (e.g., *Map 1*).
- **Concrete Symbolic**: This is the mode of building (first cycle) and working with (second cycle) conceptual understandings as part of a scientific framework. Within the first cycle, concepts may be treated in a personally relevant way alongside the emergence of scientific understandings. Within the second cycle, students are able to work with propositions in a science-based context and demonstrate a more complex level of thinking.
- $\mathbf{U_{1CS}}$: A few independent concepts related to the main concept are listed as a single strand or as a number of short strands. If linked, there is a repetition, or implied repetition, of the main concept. (e.g., *the outer strands of Map 5*).
- $\mathbf{M_{1CS}}$: A number of concepts are linked without the need to repeat the main concept. More than one idea about the main concept is contained in the strand indicating that students are able to think about a number of aspects of one theme related to the main concept at the same time. These ideas are expressed independently, in a list-like way (e.g., *Maps 2 and 3*).
- $\mathbf{R_{1CS}}$: A feature of the main concept is developed using linked ideas. This development can be equivalent to a story is being told indicating that students have seen the links between separate propositions. There may be some initial attempts at branching, however, these are not fully developed ideas (e.g., *the right hand strand of Map 4*).
- $\mathbf{U_{2CS}}$: A number of strands comprising linked ideas are used to describe a feature of the main concept. Students are able to identify a feature by linking concepts and can elaborate on one aspect of that feature. Branching is used once to elaborate the particular term or idea (e.g., *Maps 5, 6 &7).*
- $\mathbf{M_{2CS}}$: More than one meaningful branching point is used to develop features of the main concept. Links are identified between these features although responses still maintain a direction of 'flow' of ideas that is in one direction from the main concept (e.g., *Map 9*).
- $\mathbf{R_{2CS}}$: Development of features of the main concept extends to the inclusion of reversible links. The framework of concepts is constructed so that the 'flow' of ideas can occur in two directions (e.g., *Maps 8 &10*).

5 Conclusion

The structural underpinnings of the SOLO model provided a potentially informing framework from which to interpret variations in structural complexity of concept maps. Descriptors for modes and levels have been proposed that place increasingly complex maps within a developmental sequence. The identification of two cycles within the concrete symbolic mode reinforces findings for a number of mathematics and science concepts where studies have detailed the characteristics of the cycles as students move from the perceptual focus of the ikonic mode through the construction of concrete concepts (first cycle) and their application in reality bound problems (second cycle). The analysis of concept maps in this study has implications for applications of the model and for providing additional information about cycle characteristics. In addition, responses coded within the first cycle of the concrete symbolic mode were characterized by the use of ikonic imagery as a reference point for the construction of science concepts. The observation of such ikonic support, or multimodal functioning, is also consistent with studies reported in the literature. Whilst the SOLO model can be used as an assessment framework for concept maps based on visual appearance and propositional groupings, further investigations are needed in order to continue to refine descriptive categories for modes and levels, and to investigate further parallels between the structure of the model and the structure of maps. Such investigations would need to be based on maps prepared by students across a broad age range and for a range of curriculum areas. This study has hinted at benefits for both the SOLO model and for concept maps. Continued application of the model has the potential to chart map constructs, such as progressive differentiation, and the qualitative changes that are evident in student learning over time. Continued analyses of concept maps also have the potential to provide important information for the model concerning the way students work with concepts during important level transitions.

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