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Extending the Power of the Concept Map

This pilot study introduces a scale to assess structural knowledge in concept maps. The need to increase our understanding of structural knowledge through improved assessment is made evident in a review of research that indicates that its quality is related to problem-solving abilities. The new scale is derived from Biggs and Collis' (1982) Structure of the Learning Outcome (SOLO) taxonomy and Rumelhart and Norman's (1978) modes of learning (structuring, accretion, and tuning). It is applied to link descriptions in an enhanced concept map structure that has been dubbed the "concept map+." Eight levels of link quality can be recognized with the new scale. This builds on the original concept map assessment scale of Novak and Gowin (1984) where just three types of link quality were acknowledged.

Cette étude pilote présente une échelle pour l'évaluation des connaissances structurelles dans les cartes conceptuelles. Une analyse de la recherche ayant révélé que la qualité des connaissances structurelles est liée aux habiletés de résolution de problèmes, il est évident qu'il faut améliorer nos méthodes d'évaluation pour mieux comprendre ces connaissances. La nouvelle échelle est basée sur la taxonomie de Biggs et Collis (1982) sur la structure des résultats d'apprentissage (Structure of Learning Outcome, SOLO) et sur les modes d'apprentissage de Rumelhart et Norman (1978) : structuration, accroissement et adaptation. Elle est appliquée aux descriptions de liens dans une structure perfectionnée de cartes conceptuelles que l'on appelle ?concept map+.?. Cette nouvelle échelle distingue huit niveaux dans la qualité des liens, augmentant ainsi l'échelle d'évaluation originale de Novak et Gowin (1984) qui comportait seulement trois niveaux de qualité des liens.

The concept map was introduced by Novak and Gowin (1984). Since then it has been put to good use in the classroom as a learning and assessment tool. Proponents of concept maps hold that the linking words that connect their concepts are expressions of the mapper's structural knowledge (their understanding of the relationships between the concepts). Structural knowledge has been associated with problem-solving ability (Chi & Glaser, 1985; Gordon & Gill, 1989; Jonassen, Beissner, & Yacci, 1993; Robertson, 1990). The importance that educators place on problem-solving ability underscores the need to develop methods to assess structural knowledge. This article introduces an eight-point scale to assess the quality of students' structural knowledge. The scale provides a more sensitive and fine-tuned tool than the three-point concept map assessment scale that Novak and Gowin developed. It is applied to an extension of the concept map, the concept map+.

The concept map+ is sufficiently complex that it cannot be produced or marked as quickly as the concept map. Consequently, it will never replace the concept map in the classroom. However, teachers and students who take the time to become familiar with the concept map+ might mark and produce them with sufficient rapidity that they can find several uses for them in the class-

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room. Organizing knowledge for essay-writing purposes (in the concept map+ concepts are arranged into relatively discrete regions; it is held that these regions represent paragraphs; it is also held that link descriptions that connect concepts represent sentences within paragraphs) springs to mind, as does test preparation (making the links between concepts explicit reveals weaknesses in understanding). Beyond the classroom, the scale of the concept map+ provides a means for educational researchers to assess the quality of structural knowledge at a level that exceeds the capabilities of the Novak and Gowin (1984) scale. It is the latter, research-based capability that is of interest here.

Descriptions of the concept map and the concept map+ are presented in the following section of this article. Then a series of linking statements are assessed with the new scale. Descriptions of the processes of link assessment are presented to make the mechanics of the new scale available to the reader.

An Introduction to the Concept Map and the Concept Map+

Examples of the uses that educators have found for concept maps include to plan curricula, to evaluate learning, to identify erroneous thinking, and to make judgments about the quality of students' understanding (Barenholtz & Tamir, 1992; Edmondson, 1993; Edmondson & Smith, 1996; Fisher, 1996; Liu, 1994; Morine-Dershimer, 1993). Edmondson and Smith maintained that concept maps have the potential to increase recall and to maximize the usefulness of knowledge. Plotnik (1997) noted that concept maps have been used to brainstorm, to assess understanding, and to communicate complex ideas. Additional uses for concept maps as noted by Hale (2004) include the connection of new ideas to extant knowledge and the connection of ideas within it. These uses are made possible by an assumption of Gaines and Shaw (1995) and Lanzig (1997) that concept maps are used in education to represent knowledge.

Concept maps are part of a family of tools known as graphic organizers that "portray relationships between key terms that are taken from a learning task" (Moore & Readance, 1984, p. 11). Examples of graphic organizers (other than concept maps) that the reader may be aware of include Fishbone diagrams, Venn diagrams, Spider maps, and Mind Maps (an index of various types of graphic organizer can be found at: http://www.sdcoe.k12.ca.us/score/actbank/torganiz.htm). Structurally, concept maps are closely related to the mind map. Palmer (2002) acknowledges this similarity. noting that the similarity is such that the terms *concept map* and *mind map* are used interchangeably. According to Palmer (2002) and Lanzig (1997), the difference between mind maps and concept maps lies in the number of central concepts that they contain. In the mind map there is a single central idea, and related or child ideas are drawn around it. Additional ideas are drawn around each child idea to generate a graphic organizer that has a tree-type structure. Figure 1 illustrates the typical mind map structure. It contains three child concepts (child concepts 1, 2, and 3) that are linked to a single central concept. Additional ideas (concepts 1a, 1b, 1c, and 1d, for example) are arranged around the child ideas that they are related to (child concept 1 in this case). Concept maps may contain several central ideas as illustrated in Figure 2 (the concepts A1, B1, and C1 are the central concepts of Figure 2). Subordinate concepts are arranged in a hierarchical fashion beneath these central concepts to form a networked

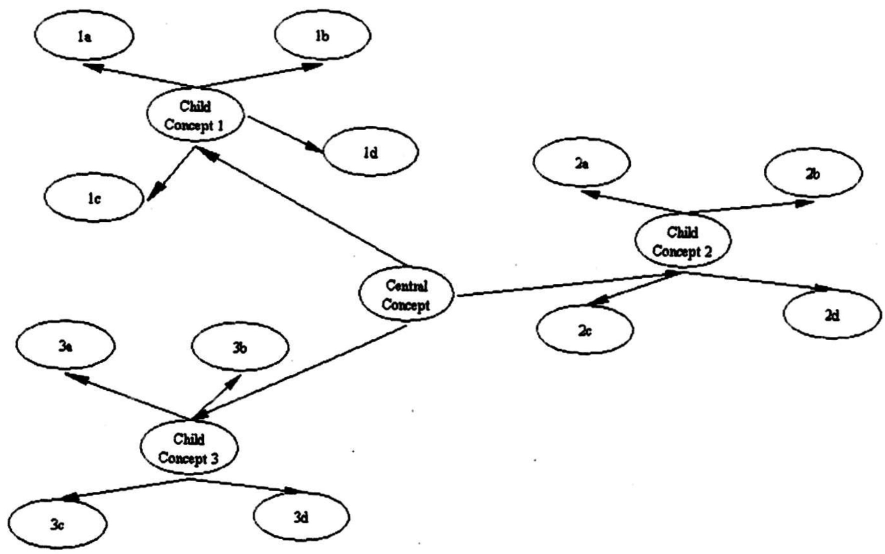


Figure 1. Typical mind map structure.

structure. For example, the subordinate concepts C2, C3, C4, C5, and C6 are arranged hierarchically beneath the central concept C1.

Figure 2 presents the typical structure of a Novak and Gowin (1984) concept map. Note how the concepts are arranged hierarchically to form regions that are relatively discrete from one another. The A, B, and C typings represent the regions of Figure 2 and the concepts, A, (B1, C1), B2 (C2), B3 (C3, C4), and C5(C6) represent the five hierarchical levels. Figure 3 builds on the introduction to concept maps that Figure 2 provides. It contains complete descriptions of the concepts and links of Figure 2. A review of the arrows (indicating the presence of relationships between concepts) and linking words (expressions of the mapper's understanding of those relationships) of Figure 3 reveals that it is a concept map about the structure and nature of concept maps.

The concept map+ is structurally identical to the concept map except that the relationships it contains are expressed in one or two complete sentences rather than one or two linking words. Figure 4 is provided to illustrate the difference between the links of a concept map and a concept map+. The top half of the figure portrays a concept map link between the concepts *Sunlight* and *Plant*. The bottom half of the figure illustrates the same link in concept map+ format. In the top (concept map) half of the figure, the linking word *Photosynthesis* is positioned above the linking arrow and close to the link that it represents. Positioning linking words above or close to the connecting arrows of links is typical of concept maps, as is the provision of just one or two linking words. Representing relationships between concepts with one or two linking words lends concept maps to rapid production; it also facilitates study for when the learner reflects on a linking word (or words), recall of the relationship between concepts is stimulated. From an assessment perspective, one or two linking words provide a rather lean source of information for ascertaining the accuracy and quality of a mapper's understanding.

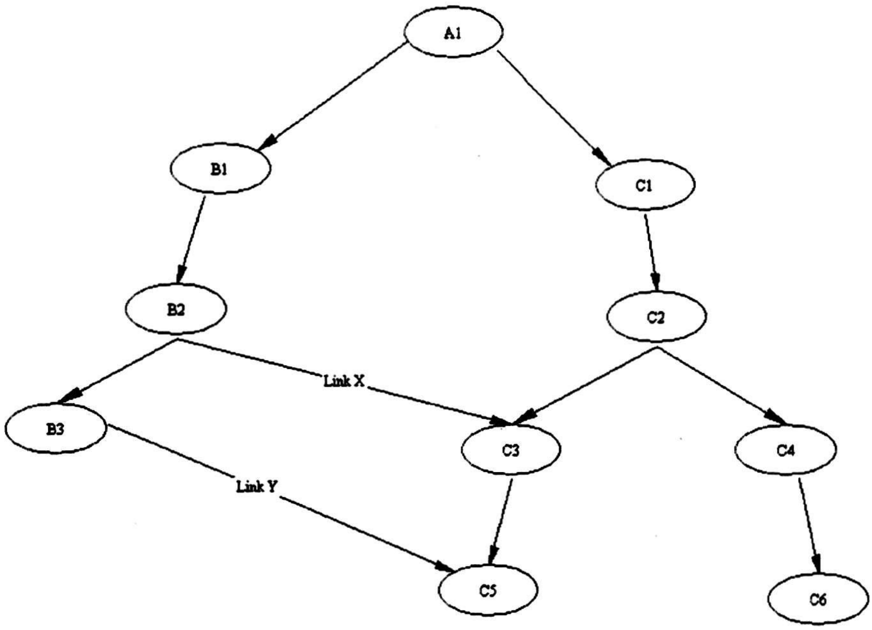


Figure 2. Typical concept map structure.

The bottom half of Figure 4 illustrates the potential that the concept map+ holds for overcoming the limited assessment information that linking words provide. In this typical concept map+ link structure, a number is placed above the linking arrow and at the bottom of the map. Beside the bottom number a

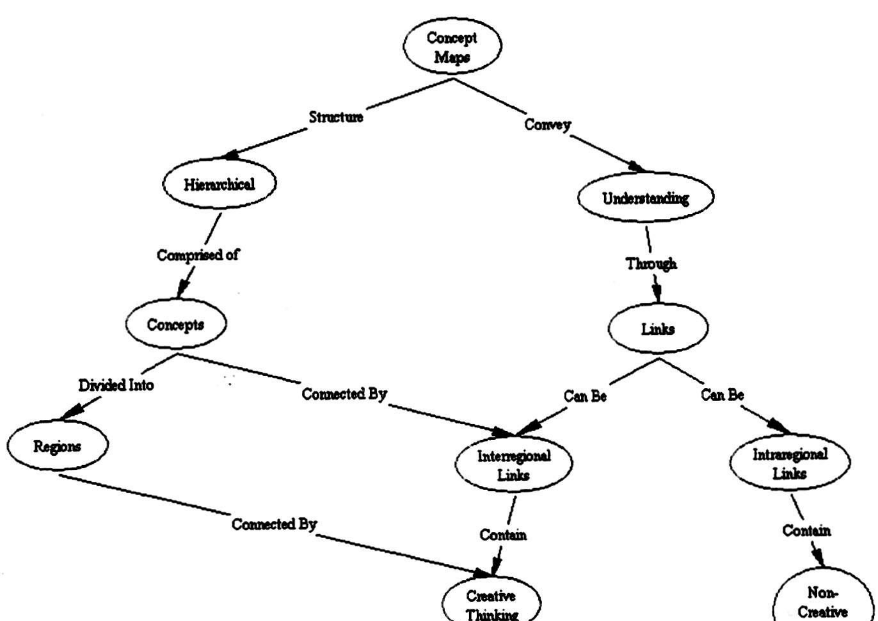
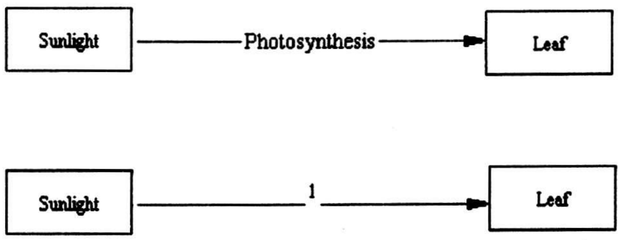


Figure 3. Typical concept map structure with links.



1. Photosynthesis is the reaction that associates sunlight with plant leaves
1. Photosynthesis ocurs in chlorophyll in leaves
2. It is kick-started by energy in sunlight
3. CO_2 and H_2O are converted to O_2 and glucose
4. CO_2 and H_2O are respiration waste products
5. Glucose fuels respiration
6. Oxygen is released into the atmosphere

Figure 4. Comparison of concept map linking words and concept map+ linking statement.

complete description of the mapper's understanding of the link relationship is provided in the linking statement "photosynthesis is the reaction that associates sunlight with plant leaves." Items of data (numbered items) appear beneath the linking statement. Each datum presents a component of the relationship of the link and is worded to indicate how it is associated with other items of data. Associations between data are important as they indicate how they were combined to form complete expressions of understanding in the linking statements.

On reading the above, the reader may be of the opinion that an organizer that provides so much textual information should not be referred to as a graphic organizer and that a new term such as *graphic organizer+* might better classify the concept map+. Regardless of the accuracy of the terminology, it is convenient to use the term graphic organizer to describe the concept map+ in this work.

Linking words (and, I argue, link descriptions) are said to represent the mapper's structural knowledge or understanding of why the concepts of a link are related. Structural knowledge holds considerable import for educators. In addition to indicating why concepts are related, it also, according to a Jonassen et al. (1993) citation of a Mandler (1983) study, gives meaning and structure to knowledge. That is, structural knowledge influences the position of concepts in concept maps and reflects the quality of the understanding that is contained in the links (relationships) that connect them. The importance of structural knowledge is further emphasized in research that considers its relationship to problem-solving ability. Jonassen et al., (1993) considered it important for problem-solving success, and Chi and Glaser (1985) deduced that it had a positive influence on problem-solving ability. Gordon and Gill (1989) determined that students' problem-solving abilities increased as their knowledge structures came to resemble the instructor's. Robertson (1990) even concluded that having the right structure was more important than ability when it came to solving physics problems. The influence that structural knowledge has on problem-solving ability underscores the importance of developing methods to assess its quality.

The Novak and Gowin (1984) assessment method considers the quality of structural knowledge. It is described in the following section. A description of the new scale follows this. It improves on the Novak and Gowin technique as it is more sensitive to the quality and nature of structural knowledge.

The Novak and Gowin Concept Map Assessment Technique

Several methods have been developed to assess the quality of structural knowledge in concept maps. Their scales involve the enumeration of concepts, links and cross links (Ruiz Primo, Shavelson, Schultz, n.d.). Novak and Gowin (1984) introduced the first concept map assessment technique. In addition to link enumeration, Novak and Gowin considered the accuracy of linking words. A description of the Novak and Gowin method is presented below. It is used as a platform from which the advances of the new method can be presented. The advances pertain first to an increased ability to differentiate among link quality. Novak and Gowin recognize three levels of link quality; the new method recognizes eight. Additional advances pertain to increases in the accuracy of link quality assessments that the concept map+ makes possible. The latter advances are made possible as the concept map+ provides more structural knowledge to the rater than the concept map.

The scale of the Novak and Gowin (1984) assessment technique is presented below; it takes the validity of linking words into account and the notion of regions.

1. Give a score of 1 to all valid intraregional links. Subtract a score of 1 for each invalid intraregional link.
2. Give a score of 10 to cross-links that contain examples of creative thinking. Score non-creative cross links as intraregional links.
3. Allot a score of 3 to each level of the hierarchy

In the above, the term *intraregional links* refers to links that connect concepts within the same region of a map. Cross links connect concepts across different regions. The relationships of cross links are said to be more likely to contain creative thinking than the relationships of intraregional links. Creative thinking is more difficult than noncreative thinking, and so concept maps contain fewer cross links than intraregional links. Figure 2 contains just 2 cross links, link X and link Y. In recognition of the difficulty of creative thinking, the Novak and Gowin technique awards cross links a higher score than intraregional links. Cross links that do not contain creative thinking are awarded the same score as intraregional links. Figure 3 reveals that the cross links of Figure 2 do not contain creative thinking.

A Concept Map+ Assessment Technique

Concept map+ graphic organizers differ from concept maps in that they contain complete expressions of structural knowledge or linking statements rather than linking words. The advantages (for assessment) that linking statements and their data hold over linking words are illustrated below in a link that involves the concepts *Clouds* and *Colour* and the relationship *"why clouds are white in colour."* In a concept map this relationship might well be represented by the linking words *refract light*. The concept map+ link below represents this relationship with the linking statement, "clouds are white because they refract all the wavelengths of visible light that hit them to an equal extent." The items of data presented beneath the linking statement with the intent of indicating how the understanding expressed in the linking statement was acquired.

Clouds are white because they refract all the wavelengths of visible light that hit them to an equal extent.

1. The visible spectrum that reaches us from the sun is made up of a swath of wavelengths of light of various colours that together make up white light.
2. The colours of the visible spectrum are made up of bands of contiguous wavelengths of light.
3. From their highest to their lowest wavelengths the bands of light in the visible spectrum pass through the following colour sequence; red, orange, yellow, green, blue, indigo, violet.
4. In combination the bands of light of the visible spectrum make up white light.
5. When visible light from the sun hits rain clouds the water drops in them refract all of the bands of light.
6. When light that has been refracted from clouds hits the eye it appears white as it comprises equal amounts of each band of the visible spectrum.

In the above link, the linking words of the concept map leave much to the imagination of the rater. That is, the words *refract light* do not actually reveal that the mapper understands that all wavelengths of the visible spectrum are refracted and that in combination they make up white light. The rater has to take it on good faith that this is what the mapper means. In comparison, the mapper's understanding is revealed to a greater extent in the linking statement and data of the concept map+. Here the rater can readily determine that the mapper understands that all wavelengths of the visible spectrum are refracted and that in combination they are white in appearance when they hit the eye.

A method to assess structural knowledge in the concept map+ can now be introduced. It was developed by combining the Biggs and Collis (1982) SOLO (structure of the observed learning outcome) taxonomy with the restructuring, accretion, and tuning modes of Rumelhart and Norman (1978). From a research perspective, these works might be thought of as being rather old. However, despite their age, they are still considered to be accurate. When the two works are combined they provide a scale that, in my opinion, is highly relevant to current educational research, as improving our understanding of structural might well, with additional work, shed light on the assessment of students' problem-solving abilities.

The assessment scale that results from the combination of the SOLO taxonomy and the modes of Rumelhart and Norman (1978) recognizes eight levels of understanding in concept map+ links. Examples of each of the eight link types of the scale are presented below. The first five example links are adaptations of the five levels of the SOLO taxonomy. From lowest to highest these levels are: prestructural, unistructural, multistructural, relational, and extended-abstract. The remaining link types of the new scale (extended-unistructural, extended-multistructural, extended-relational) were derived from the addition of the learning modes of Rumelhart and Norman to the SOLO taxonomy.

The example links concern the concepts *Body* and *Infection* and the relationship "how do humans fight infection?" I developed them from a short text:

> Humans fight infection with natural barriers such as the skin and mucous membranes that prevent bacteria from entering the system. A second way that humans fight infections is by way of the immune response system. Should a foreign body enter the system, a highly choreographed immune response involving macrophages, T-cells and antibodies takes place to inhibit the ability of the invading entity to grow and multiply. The symptoms of the common cold are an expression of the immune system response.

The prestructural link is exemplified by the presence of incorrect thinking in the linking statement and/or one (or more) of the items of data. A prestructural response to the question of how humans fight infection might be:

> *Linking statement*—Cold bacteria cause an increase in body temperature.
> *First datum*—Cold bacteria cause an increase in body temperature.

The linking statement and datum contain incorrect thinking, for bacteria in and of themselves do not affect the temperature of the body. It is the immune system response to invading bacteria that causes an increase in body temperature.

In a unistructural link a single relevant item of data is used to associate the concepts involved. The linking statement and datum of such a link are presented below.

> *Linking statement*—Humans have natural barriers to infection.
> *First datum*—Humans have natural barriers to infection.

When as in this case the datum is exactly the same as the linking statement, it is assumed that the mapper is unaware of additional factors that influence the relationship. If the linking statement and datum differ, it is assumed that the mapper simply failed to express all the information that he or she was aware of in the linking statement or the datum. Links are still rated at the unistructural level when the linking statement and datum differ.

During the creation of multistructural links, two or more items of data are held in working memory simultaneously. The relationship between them is not understood to the extent that it can be expressed as a single cohesive statement and the components of the link appear in the linking statement as separate units of information. The linking statement and data of a multistructural link are presented below.

> *Linking statement*—Humans fight infection with natural barriers and they also fight infection with their immune systems.
> *First datum*—They fight infection with natural barriers such as the skin and mucous membranes.
> *Second datum*—They fight infection with their immune systems.

The components of this linking statement concern "natural barriers" and "mucous membranes." They are conjoined in the linking statement by the phrase "and they also." Conjoining phrases such as "and they also," "and it is also," and "as well as" are indicative of multistructural links. They indicate a failure to integrate data in working memory. That is, they indicate that the relationship between the data under consideration is sufficiently complex that the mapper could not integrate it to form a single cohesive statement. The integration of data begins with links of relational quality. Once integration has occurred, data appear in the linking statement as a seamless expression of the mapper's understanding. The linking statement and data of a relational link that concerns the response to infection are presented below.

Linking statement—Humans have two lines of defense against infection, natural barriers and the immune system.
First datum—Natural barriers such as the skin and mucous membranes help humans fight infection.
Second datum—Macrophages and antibodies are produced by the human immune system to help humans fight infection.

In links of extended-abstract quality, data from inside and outside the text (the instruction) are integrated creatively to form a linking statement. Multiple logical deductions and inferences that involve new hypotheses, abstract principles, and analogies might be found in the linking statements of this link type.

Linking statement—Holistic treatments that boost the immune system such as aromatherapy and Qi Gong can assist humans in the fight against infection as they serve to enhance the functions of the immune system in unknown ways.
First datum—When the immune system is compromised the response to infection is impaired.
Second datum—Aromatherapy treatments can augment or boost an impaired immune system by easing congestion to relieve breathing and thereby facilitate the body's capacity to recover.
Third datum—Qi Gong treatment realigns the body to relieve patterns of stress and impaired function in ways that the medical establishment does not fully understand.
Fourth datum—Alternate treatments like aromatherapy and Qi Gong work to optimize the immune system and its response to infection.

The reader might well argue that the above link fails to associate information about alternative medical treatments with the instruction creatively. However, as the interpretation of creativity is a personal, subjective matter, I submit that a link might reasonably be identified as being of extended-abstract quality when it contains information that has been integrated with the instruction as a rater had not previously considered. This submission assumes that the rater has considerable knowledge of the subject matter. It is worth noting that in addition to the creative integration of information that is external and internal to the instruction, extended-abstract links may integrate information that is presented in the instruction in creative ways (ways not provided in the instruction).

In addition to the five levels of the SOLO taxonomy, the new method makes division among link quality by considering the restructuring, accretion, and tuning modes of Rumelhart and Norman (1978). For our purposes, restructuring refers to learning wherein structures containing knowledge that is new to the learner are formed in memory. Accretion refers to learning that adds information to extant structures in the learner's memory. Tuning refers to learning that associates new knowledge with extant structures in creative ways. The example unistructural, multistructural, and relational links described above involve the repetition of information that is presented in the instruction. As such they represent the restructuring mode of learning. The creative addition of information to the instruction as per the requirements of the extended-abstract link represents the tuning mode. Links that add information to the instruction in noncreative ways match the description of the accretion mode. Three types of accretion link types might be found in a concept map+. The first contains one item of data that is associated with the instruction in a noncreative fashion. The second contains a linking statement that describes information from inside and outside the instruction in a sequential manner as per the nature of the multistructural link. The third accretion link type adds one or more items of data to the instruction as per the integrative nature of the relational link. For reasons of convenience (and linearity with the SOLO taxonomy), the three accretion link types are called extended-unistructural, extended-multistructural, and extended-relational links.

Examples of extended-unistructural, extended-multistructural, and extended-relational links follow. In each case a single item of data "by deliberately avoiding sources of contagion, humans can fight infection" is added to the instruction. In the case of the extended-unistructural link the extraneous datum might appear thus:

> *Linking statement*—Humans can fight infection by avoiding sources of contagion.
> *First datum*—Humans can fight infection by avoiding sources of contagion.

In the extended-multistructural link the datum of extant knowledge might manifest as:

> *Linking statement*—Humans fight infection with natural barriers and they also fight infection with their immune systems and as well by avoiding their source.
> *First datum*— Humans fight infection with natural barriers such as the skin and mucous membranes.
> *Second datum*—Humans fight infection with their immune systems.
> *Third datum*—Humans can fight infection by avoiding sources of contagion.

In the case of the extended-relational link the datum is added to the instruction in a seamless fashion as follows.

> *Linking statement*—In addition to lines of defense such as natural barriers and the immune system, humans can avoid animals and other sources of contagion in the fight against infection.
> *First datum*—Natural barriers such as the skin and mucous membranes help humans fight infection.
> *Second datum*—Macrophages and antibodies are produced by the human immune system to help humans fight infection.
> *Third datum*—Infection can also be fought by avoiding animals and other sources of contagion.

Differences in the quality of thinking that is required of the restructuring, accretion, and tuning modes can be used to guide the ordering of the eight link types along the new scale. It is held that the highest level of thinking is required to make the creative associations of the tuning mode. Thus extended-abstract (the only tuning mode link type) links can be placed at the top of the scale above accretion and restructuring links. In comparison, the accretion mode requires lower-level, noncreative thinking. However, the link types of the accretion mode do contain higher-level thinking than the restructuring links types, for they add information to the instruction rather than simply repeating it. Differences in the quality of thinking of the learning modes mean that when the links of the new scale are assembled from lowest to highest quality they form the following eight-point scale:

The eight point scale of the new method
Prestructural links: the linking statement contains an incorrect inference or the inference is correct but at least one item of data is incorrect or irrelevant to the link.
Unistructural links: the linking statement contains a correct inference that involves a single item of data. The material involved was presented in the instruction.
Multistructural: the linking statement is a list of conjoined items of data. No inference was formed to integrate the data. The data is relevant and was presented in the instruction.
Relational: the linking statement contains a correct inference that integrates relevant items of data. The material involved was presented in the instruction.
Extended-unistructural: the linking statement contains a correct inference that involves a single item of data. The material is relevant to the instruction but was not presented in it.
Extended-multistructural: the linking statement is a list of conjoined items of data. No inference was formed to integrate the data. The data is relevant to the instruction. At least one of the data items was not presented in the instruction.
Extended-relational: the linking statement contains a correct inference that involves relevant items of data. At least one of the data items was not presented in the instruction.
Extended-abstract: the linking statement contains a correct inference (or multiple inferences) that involves relevant items of data. At least one item of data was not presented in the instruction. It is associated with data from the instruction in a creative fashion.

The relationship between learning modes and link types is represented in Table 1.

Enumerating link data makes possible further division among link types. For example, a relational link with two items of data can be differentiated from one with three items of data by adding the number of data items to the method's nomenclature. The first of these links would be a relational-two link and the second would be a relational-three link. Differentiation among multistructural and extended-abstract link types is also made possible by counting items of data.

The above reveals that the new method builds on the Novak and Gowin (1984) technique in two ways. First, it can distinguish among eight levels of link quality as opposed to three. Second, it can recognize three types of thinking (structuring, accretion, and tuning) as opposed to two (noncreative and creative).

An Examination of Example Maps

To test the viability of the method, 27 grade 9 biology students were asked to generate concept map+ graphic organizers of a target text that concerns oil spills. Two of the 27 graphic organizers the students produced are examined here. They are referred to as the maps of students 1 and 2 and they are presented in Figures 5 and 6 respectively. These particular graphic organizers

Table 1
Learning Modes and Link Types

Structuring Mode	*Accretion Mode*	*Tuning Mode*
Prestructural	Extended-unistructural	Extended-abstract
Unistructural	Extended-multistructural	
Multistructural	Extended-relational	
Relational		

were selected for examination because, in my opinion, when the assessment of their links is described it best reveals the mechanics of the application of the scale to the reader. They were also selected because they contain at least one example of each of the link types that the 27 students produced.

Each of the students of the biology class was a member of the secondary-level gifted program of a School Board in Ontario, Canada. Their teacher John was the school's head of science. He was one year away from retirement and had until the year before the study ran served at a board-wide level overseeing the design of innovative lesson plans for various curricula. John told me that in his opinion, this particular class contained some of the brightest and most motivated students that he had encountered in his 30-plus years of teaching.

Prior to this exercise, the students had never produced concept maps or concept map+ graphic organizers. The day the study began I presented them with a 20-minute lecture on the creation of concept map+ graphic organizers. Immediately following the lecture the students produced a practice organizer on a topic of their choice. On the second day (a Friday) they read the target text (downloaded [but no longer available] from the University of Southampton: http://www.soton.ac.uk/~engenvir/environment/water/oil.slicks.html) and began to map their understanding of it. The students were told to use *Oil spills* as the title concept of their graphic organizer and include the concepts *Clean Up* and *Tankers* somewhere within it. Other than this, they had free rein over the creation process.

Although this was only the students' second attempt at creating concept map+ organizers, almost all had grasped the main ideas involved. They set about the task of creating their organizers enthusiastically and quite noisily. They asked few questions about the mechanics of link creation. The weekend was made available for the students to complete the organizers. All 27 organizers were handed in on time on Monday the following week.

Table 2 presents an example of each of the link types produced in the maps of students 1 and 2 (Appendix). It also presents an example of each of the link types that the 27 students of the grade 9 biology class produced. Link 1 of student 2 might appear to be an extended-relational-three link as it contains three items of data that have been integrated in the linking statement. However, while this link adds context to the graphic organizer, its relationship to the instruction is (in my opinion) tenuous. Students 1 and 2 produced a number of links whose information is at best only contextually related to the instruction. The goal in this study was to determine whether raters could effectively handle the main constructs of the method. That is, could they ascertain if a link represented the restructuring, accretion, or tuning modes;

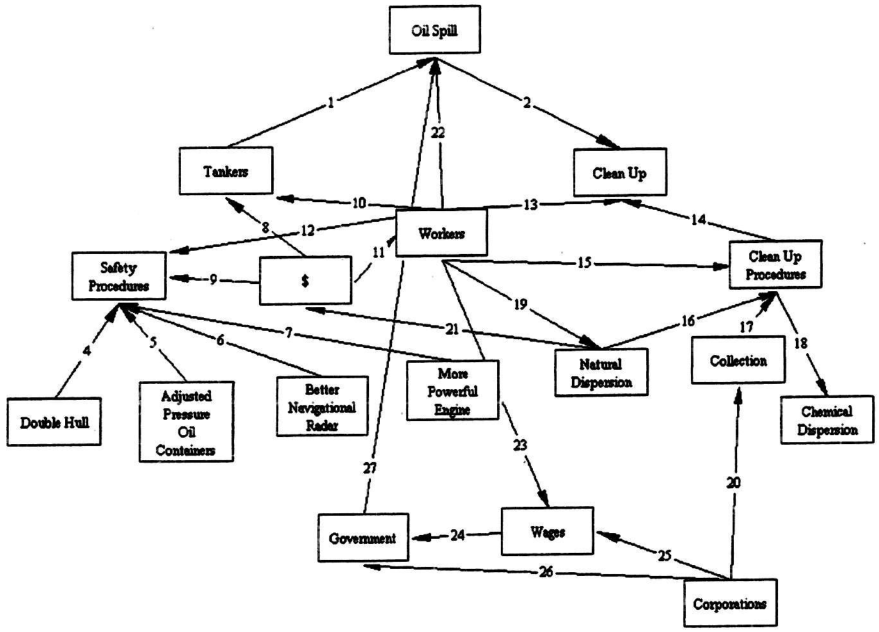


Figure 5. An example map (student 1).

count the relevant items of data; and decide whether they were integrated in the linking statement. Links that add context to the organizer do not match the main constructs of the scale. They were excluded from the analysis and referred to as general knowledge links.

Table 2
Examples of Each of the Link Types Produced in This Study

Link	*Linking Statement*	*Rating*
1 (Student 2)	Shipping industry manufactures tankers (a) get materials (b) put parts together (c) sell to companies	General Knowledge
17 (Student 1)	Collection is another procedure (a) it is 100% effective (b) it gets all oil (c) oil can be reused	Prestructural
6 (Student 2)	Oil spills cause pollution (a) spread through environment	Unistructural
4 (Student 1)	A double hull is a safety procedure (a) crashes must be harder to puncture both hulls (b) oil containers are less likely to be breached	Relational-2
3 (Student 1)	Safety procedures are needed for tankers to be effective	Extended Unistructural
7 (Student 1)	More powerful engines will make ships safer (a) faster turning will be possible (b) obstacles can be better avoided	Extended Relational-2

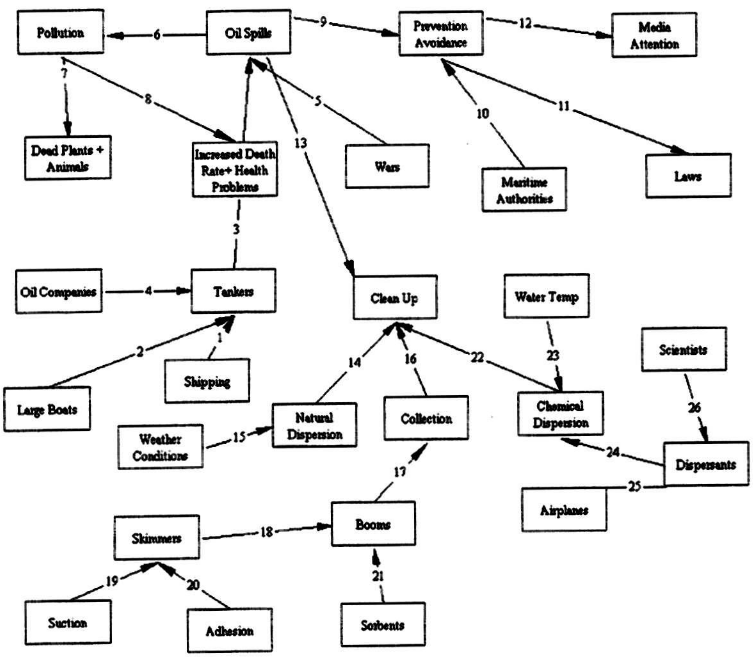


Figure 6. An example concept map (student 2).

General knowledge links were excluded from the interrater reliability assessment of the new scale as I felt that asking raters to deal with them in addition to learning the link types of the scale would place them under unreasonable cognitive strain. I identified and highlighted general knowledge link in maps 1 and 2 before the start of the assessment process. The maps were then handed to two raters who were told to exclude the highlighted links from the assessment. Oral and written instructions were provided to the two raters to help them learn to use the new method. The raters and I reached agreement on 32 of the 41 non-general knowledge links of the two maps. Expressing the number of links that the raters agreed on as a percentage of the total number of links [(Total # agreements)/(Total # Observations) * 100] gives an interrater reliability of 78%. This result could probably have been improved on had the raters been given time to collaborate on two or three practice maps before they began the rating process.

Link 17 of student 2 is an example of a prestructural link. It refers to a relationship between the concepts *Collection* and *Clean Up Procedures.* Its data stipulate that collection removes all the oil that is spilled. It also concludes that collection is a 100% effective clean-up method. The text does state that oil is completely removed from the environment once it has been collected. However, it does not say that all the oil that is spilt can be collected. The mapper made an erroneous assumption. Raters identify prestructural links by looking for errors of comprehension in the linking statement or in (one or more) items of data.

Link 6 of student 2 is an example unistructural link. It refers to a relationship between *Oil Spills* and *Pollution.* It contains one item of data that states that oil spreads through the environment. Its linking statement concludes that oil spills cause pollution. The quality of understanding in this link is identified in the same way that it is identified in other link types. First, the rater reviews the link to determine how the data are associated in the linking statement. Once the means of association is known, it is used to compare the link to the scale of the method. In the case of link 6 of student 2, review indicates that the mapper subsumed the spread of oil within the notion that oil causes pollution. It also indicates that this information was presented in the text. According to the scale of the method, links containing one item of data that was presented in the text are unistructural links.

The fourth link of student 1 is an example-relational link that concerns the relationship between *Double Hull* and *Safety Procedures*. Its data indicate that breaching both layers of a double hull requires a more severe crash than is the case for a single hull. Consequently the chance of oil leaking into the environment is reduced when ships have a double hull. On reviewing this link the rater can deduce that its data are integrated in the linking statement, which stipulates that "a double hull is a safety procedure." The scale of the method indicates that links that integrate two items of data that have been presented in the instruction are relational-2 links.

Link 3 of student 1 is an example-extended-unistructural link. It concerns the relationship between the concepts *Safety Procedures* and *Tankers*. There is just one item of data in the link, and it is exactly the same as the linking statement. The datum contains the correct inference that safety procedures are needed for tankers to be effective. The target text only hints at the requirement for safety procedures. It does not stipulate why they are needed. Links that build on the text in noncreative ways with a single datum are extended-unistructural links.

Link 7 of student 1 is an example-extended-relational link. It concerns the relationship between the concepts *More Powerful Engines* and *Safety Procedures*. Its data simply repeat information that is provided in the text "more powerful engines will enable faster turning" and "more powerful engines will allow for better avoidance of obstacles." The linking statement builds on this information by stating that more powerful engines make for superior ship safety. Review of the linking statement and data enables the deduction that the mapper integrated knowledge of faster turning and better obstacle avoidance to conclude that this makes for improved safety. Integrating two items of data in a manner that builds on the text makes this link an extended-relational link.

In all the example links of students 1 and 2, the same reasoning process is used to determine the quality of understanding that they contain. First, the correctness of the data and linking statement is considered. Inaccuracy means that the link is prestructural. Accuracy means that the link has to be considered further. The number of items of data have to be counted next, and how they are represented in the linking statement (are the data integrated or conjoined?) has to be considered. A single item points to a unistructural link. Data that are conjoined in the linking statement suggest a multistructural link. Links of relational quality contain data that are integrated in the linking statement.

The rater is also obliged to consider whether the data and linking statement repeat the text or build on it creatively or noncreatively. If information found in the text is repeated, then the rater assumes that the link is a restructuring link and that it must be of unistructural, multistructural, or relational quality. If the link builds on the text noncreatively, it is an accretion link. Extended-unistructural, extended-multistructural, and extended-relational links are the accretion links. Links that build on the text creatively are tuning links. The extended-abstract link is the only tuning link type. Working through the above process reveals the accuracy of items of data, their number, and how they are represented in the linking statement. When the information that is derived from this reasoning process is compared with the scale of the method, the quality of understanding that is contained in a linking statement is revealed.

A small number of the links produced by the students were rated as unmarkable. This problem was probably related to the brevity of the training that the students received for this exercise. Link 22 of student 1 represents one of the two types of error that led to an unmarkable link rating. Its linking statement refers to conclusions or data found elsewhere in the map.

Linking statement—Because of many above reasons, workers are responsible for oil spills

The links and items of data that the student is referring to cannot be determined from this statement. In consequence the link is unmarkable. The second error type concerns overly fragmented data. Link 9 of student 2 exemplifies this problem.

Linking statement—Oil spills need to be prevented and avoided.
First datum—Preventing oil spills.
Second datum—Stop them from having accidents.
Third datum—If accident occurs, stop them from leaking.
Fourth datum—Avoiding spills.
Fifth datum—Plotting routes to avoid accidents.

The datum *if accident occurs, stop them from leaking* is encompassed by the datum *preventing oil spills*. The datum *stop them from having accidents* is repeated in the datum *avoiding oil spills*. Overly fragmented data that goes undetected leads to falsely elevated link ratings.

Concluding Remarks

A method is introduced to assess the quality of students' structural knowledge. The scale of the method was developed by integrating the Biggs and Collis (1982) SOLO taxonomy with Rumelhart and Norman's (1978) learning modes. The method builds on on the Novak and Gowin (1984) concept map assessment technique by recognizing eight levels of link quality as opposed to three and by considering three types of thinking (structuring, accretion, and tuning) as opposed to two (noncreative and creative). Further division among link quality is possible within the multistructural, relational, and extended-abstract link levels of the new scale by enumerating items of data.

The new assessment method is not without problems. Students can generate structuring errors during the creation of links that render them unmarkable. Two types of structuring error were generated in this study. The first involved linking statements and data that referred to information presented in other links; the second involved overly fragmented data. I suggest that a comprehensive training program will reduce the incidence of inappropriately structured links. This appears to be a reasonable suggestion, for despite the short training period that students received in this work, only a few inappropriately structured links were produced. Although general knowledge links were excluded from this study, they do not in themselves represent a problem with the method as they can in fact be rated. The issue is the extent to which the content of general knowledge links relates to the instruction. At some indiscernible point the information that a general knowledge link adds to a map becomes so remotely related to the instruction that it lacks value. That is, at some point the content of a general knowledge link ceases to be an expression of accretion. There are two ways to deal with the issue of general knowledge links. The first is to identify them prior to the rating process and exclude them from the analysis. In the case of research projects such as this, this approach is eminently feasible. The second approach is to consider that with practice, students' proficiency at concept map+ creation will become such that general knowledge links are produced only when absolutely necessary. In the latter situation it is proposed that so few general knowledge links will be produced that they will have little effect on the assessment of structural knowledge.

It should be noted that the maps that students produced for this study lacked the typical hierarchical structure of Novak and Gowin (1984) concept maps. I submit that a comprehensive training system that considers the hierarchical arrangement of concepts in addition to the structure of linking statements will result in the production of graphic organizers that differ from concepts maps only in the amount of information contained in their links. In this study, the instruction for producing concept map+ graphic organizers that the students were given was primarily concerned with the structure of linking statements. The hierarchical arrangement of concepts was not emphasized, and this is reflected in the arrangement of concepts in Figures 5 and 6. However, the arrangement of concepts in the maps of students 1 and 2 did not affect the ability to demonstrate the applicability of the new scale.

Once a concept map+ graphic organizer has been produced, it can be used as a concept map is used. It can provide a means for assessing the accuracy and quality of student work. It can also serve as a study tool, something a student takes a mental step back from to obtain an overview of the subject matter. However, concept map+ graphic organizers are not introduced here as a potential replacement for concept maps. The concept map will continue to enjoy greater use in the classroom due to the slower production times of the concept map+ and because of the additional effort that is required to become familiar with the concept map+ rating process. However, teachers who become familiar with map+ organizers will find that they can in fact be produced and rated in reasonable time. They might also find that the additional effort pays dividends in terms of the knowledge that they gain of the success of their teaching efforts and the quality of their students' understanding.

I mention a use for concept map+ graphic organizers that extends beyond the assessment of link quality. Reviewing links with an eye to the prestructural links of the new scale holds potential for remedial instruction as it reveals where understanding goes astray. Link 17 of student 2 is a typical example of this function. It concludes that oil collection is a 100% effective clean-up method, and the instructor who is aware that this is an erroneous assumption can point it out and make the student aware that although oil can be removed from the environment once it has been collected, there is no guarantee that all the oil that is spilled can be collected. The linking words of concept maps do not provide for remedial instruction in such a specific manner. They tell an instructor when a student's understanding of a relationship is incorrect; they do not reveal where the source of the error lies.

References

Barenholtz, H., & Tamir, P. (1992). A comprehensive use of concept mapping in design instruction and assessment. *Research in Science and Technological Education, 10*(1), 37-52.

Biggs, J.B., & Collis, K.F. (1982). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. New York: Academic Press.

Chi, M.T.H., & Glaser, R. (1985). Problem solving ability. In R.J. Sternberg (Ed.), *Human abilities an information processing approach* (pp. 227-250). New York: Freeman.

Edmondson, K.M. (1993). *Concepts for the development of medical curricula*. Paper presented at the annual meeting of the American Educational Research Association (Report No. TM 020 119), Atlanta. (ERIC Document Reproduction Service No. ED 360 322)

Edmondson, K., & Smith, D.F. (1996). *Concept mapping to facilitate veterinary students' understanding of fluid and electrolyte disorders*. (Report No. TM 025 698). Paper presented at the annual meeting of the American Educational Research Association, New York. (ERIC Document Reproduction Service No. ED 400 315)

Fisher, K.M. (1996). Supporting knowledge construction and reflection. *Vivek, 9*(2), 1-34.

Gaines, B.R., Shaw, M.L.G. (1995). *Concept maps as hypermedia components*. Retrieved April 5, 2004, from:http://ksi.cpsc.ucalgary.ca/articles/ConceptMaps/

Gordon, S.E., & Gill, R.T. (1989). *The formation of the use of knowledge in problem solving domains*. (Report No. AFOSR-88-0063). Washington, DC: Bolling Air Force Base.

Hale, S. (2004). *Concept mapping*. Retrieved February 20, 2004, from: http://www.dc.peachnet.edu/~shale/humanities/composition/handouts/concept.html

Jonassen, D H., Beissner, K., & Yacci, M. (1993). *Structural knowledge: Techniques for representing and acquiring structural knowledge*. Hillsdale, NJ: Erlbaum.

Lanzig, J. (1997). *The concept mapping home page*. Retrieved April 12, 2004 from: http://users.edte.utwente.nl/lanzing/cm_home.htm

Liu, X. (1994). *The validity and reliability of concept mapping as an alternative science assessment when item response theory is used for scoring* (Report No. TM 021 588). Paper presented at the annual meeting of the American Educational Research Association, New Orleans. (ERIC Document Reproduction Service No. ED370 992)

Mandler, J. (1983, August). *Stories: The function of structure*. Paper presented at American Psychological Association annual convention, Anaheim.

Moore, D.W., & Readance, J.E. (1984). A quantitative and qualitative review of graphic organizer research. *Journal of Educational Research, 78*(1), 11-17.

Morine-Dershimer, G. (1993). Tracing conceptual change in preservice teachers. *Teaching and Teacher Education, 9*(1), 15-26.

Novak, J.D., & Gowin, D.B. (1984). *Learning how to learn*. New York: Cambridge University Press.

Palmer, D. (2002). *An annotated bibliography of research into the teaching and learning of the physical sciences at the higher education level: Concept maps and mind maps*. Retrieved April 5, 2004, from: http://dbweb.liv.ac.uk/ltsnpsc/AB/AB-html/node12.html

Plotnik E. (1997). *Concept mapping: A graphical system for understanding the relationship between concepts*. (Report No. EDO-IR-97-05). Syracuse, NY: Eric Clearinghouse on Information and Technology. (ERIC Document Reproduction Service No. ED407938)

Robertson, W.C. (1990). Detection of cognitive structure with protocol data: Predicting performance on physics transfer problems. *Cognitive Science, 14*, 253-280.

Ruiz Primo, M.A., Shavelson, R.J., & Schultz, S.E. (n.d.). *On the validity of concept map-base assessment interpretations: An experiment testing the assumption of hierarchical concept maps in science*. Retrieved April 29, 2003, from: http://www.stanford.edu/dept/SUSE/SEAL/Reports_Papers/Reports%20PDF/Cresst1997no.2.pdf

Rumelhart, D.E., & Norman, D. (1978). Accretion, tuning and restructuring: Three modes of learning. In J.W. Cotton & R. Klatzky (Eds.), *Semantic factors in cognition* (pp. 37-54). Hillsdale, NJ: Erlbaum.

Appendix
Linking Statements Produced by Student 1

Link	Description	Rating
1	Tankers cause oil spills (a) tankers crash (b) oil containers are compromised (c) oil spills out	General Knowledge
2	Oil spills must be cleaned up (a) to prevent environmental impact (b) to salvage oil	Extended-Relational-2
3	Safety procedures are needed for tankers to be effective	Extended-Unistructural
4	A double hull is a safety procedure (a) crashes must be harder to puncture both hulls (b) oil containers are less likely to be breached	Relational-2
5	Oil containers with the same inner pressure as outside pressure will spill less oil (a) less oil spills (b) the disaster is less great	Relational-2
6	Better navigational radar will allow obstacles to be avoided (a) less crashes will occur	Extended-Unistructural
7	More powerful engines will make ships safer (a) faster turning will be possible (b) obstacles can be better avoided	Extended-Relational-2
8	Tankers cost $ (a) hypothetically; more $, better ship	Extended-Unistructural
9	Safety procedures cost $ (a) hypothetically: more $, better procedures (b) less $, worse procedures	Extended-Relational-2
10	tankers require workers (a) more workers, less chance of problems (b) less workers, more chance of problems	Extended-Relational-2
11	Workers cost $ (a) more $, better quality of workers (b) less $, lower quality of workers	Extended-Relational-2
12	Workers apply safety procedures (a) better quality workers = better quality procedures (b) lower quality workers = lower quality procedures	Extended-Relational-2
13	A clean up requires workers (a) higher quality workers = higher quality clean up lower quality workers = lower quality clean up	Extended-Relational-2
14	To clean up, we must follow a procedure (a) good procedure = good clean up (b) bad procedure = bad clean up	Extended-Relational-2
15	Workers must apply procedure (a) higher quality workers = higher quality application of procedure (b) lower quality workers = lower quality application of procedures	Extended-Relational-2
16	Natural dispersion is a clean up procedure (a) it is 80% effective (b) sometimes has side effects	Prestructural
17	Collection is another procedure (a) it is 100% effective (b) it gets all oil (c) oil can be reused	Prestructural
18	Chemical dispersion is a clean up procedure (a) it is sometimes effective (b) it always has side effects	Relational-2

19	Workers are not needed for natural dispersion	Extended-Unistructural
20	These cost money	Extended-Unistructural
21	This does not cost money	Extended-Unistructural
22	Because of many above reasons, workers are responsible for oil spills	Unmarkable
23	Workers are determined by how much money they keep	Extended-Unistructural
24	The government determines how much of their wages the workers keep, so government determines workers	Extended-Unistructural
25	Corporations determine how much wages workers get, so corporations determine workers	Extended-Unistructural
26	The government determines how much of their profit corporations keep, which the wages corporations pay, so the government ultimately determines the workers	Unmarkable
27	From # 22-26 above, we can conclude that the government is ultimately responsible for oil spills	Unmarkable

Linking statements produced by student 2

Link	*Link Description*	*Rating*
1	Shipping industry manufactures tankers (a) get materials (b) put parts together (c) sell to companies	General Knowledge
2	Tankers are large boats (a) designed to hold lots of oil (b) bigger ship, hard to maneuver (c) long time to slow down	Relational-3
3	Tankers cause oil spills (a) tanker crashes (b) oil leaks out	General Knowledge
4	Oil supply provided by companies (a) buy tankers (b) fill them with oil (c) send to other companies	General Knowledge
5	Wars cause oil spills (Gulf War) (a) oil used as a weapon (b) oil released into Gulf (c) burn oil wells	Relational-3
6	Oil spills cause pollution (a) spread through environment	Unistructural
7	Pollution kills plants and animals (a) Animal's habitat is destroyed (b) Animal has nowhere to survive	Relational-2
8	Pollution causes death and health problems (a) air pollution leads to breathing problems (b)water becomes poison	Relational-2
9	Oil spills need to be prevented and avoided (a) preventing oil spills (b) stop them from having accidents (c) if accident occurs, stop them from leaking (d)avoiding spills (e) plotting routes to avoid accidents	Unmarkable

10	Maritime authorities help with avoidance (a) recommend keeping at least 10 miles away from coast (b) tankers file route plans with maritime authorities (c) keep routes separate	Relational-3
11	Laws help with prevention (a) oil pollution act (b) new tankers built with double hull (c) hydrostatic pressure controls	Relational-3
12	More media will help with prevention (a) media attention can convince shipping industry to use prevention methods and technology (b) increase public awareness	Extended-Relational-2
13	Oil spills need to be cleaned up safely (a) find the safest method (b) use what is available (c) start clean up	Extended-Relational-3
14	One technique of clean up is natural dispersion (a) to clean up the oil is dispersed naturally	Unistructural
15	Natural dispersion can only be used in certain weather conditions (a) oil dispersed by waves and harsh conditions (b) waves break up the oil	Prestructural
16	Another technique is collection (a) oil is collected and removed from water and used again	Unistructural
17	Oil first contained by booms (a) surround oil, stops from spreading	Unistructural
18	oil is collected using skimmers (a) two methods of skimming to collect oil	Unistructural
19	One method of skimming is suction (a) suck oil off water (b) also suck up lots of water: 90%	Relational-2
20	Other method of skimming is adhesion (a) sweep material through spill (b) oil sticks to material (c) oil carried away from spill (d) oil squeezed out of material	Relational-4
21	Sorbents used to absorb oil collected by booms (a) can be natural or synthetic (variety of shapes—sheets, mops etc.) (c) used for small pockets usually	Relational-3
22	Last method of clean up is chemical dispersion (a) chemicals used to disperse oil	Unistructural
23	Rate of dispersion depends on water temp (a) cold water—oil changes characteristics and cannot be dispersed any more	Unistructural
24	Dispersants break up oil slick (a) break up oil slick (b) slick dilutes into water (c) can only be used on certain oils	Relational-3
25	Airplanes are used to spray dispersants (a) response must be fast (b) airplanes spray dispersants on oil	Relational-2
26	Scientists are working on ways to develop new techniques of chemical dispersion (a) a new breed of oil dispersants—living organisms that feed on oil (b) trying to find less toxic ways of dispersing	Relational-2