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Analysis of the Psychometric Properties of Two Different Concept-Map Assessment Tasks

Kenneth James Plummer
Brigham Young University - Provo

ANALYSIS OF THE PSYCHOMETRIC PROPERTIES OF TWO DIFFERENT CONCEPT-MAP ASSESSMENT TASKS

Kenneth James Plummer

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GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

Kenneth James Plummer

This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

Date	Richard R Sudweeks, ,Chair
Date	Gary M Booth
Date	Charles R Graham
Date	Patrick T Panos
Date	Stephen C Yanchar

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As chair of the candidate's graduate committee, I have read the dissertation of Kenneth James Plummer in its final form and have found that (1) its format, citations, and bibliographical styles are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

Date	Richard R Sudweeks Chair, Graduate Committee
Accepted for the Department	Andrew S. Gibbons Department Chair
Accepted for the School	K. Richard Young Dean, School of Education

ABSTRACT

ANALYSIS OF THE PSYCHOMETRIC PROPERITES OF TWO DIFFERENT CONCEPT-MAP ASSESSMENT TASKS

Kenneth James Plummer

Department of Instructional Psychology and Technology

Doctor of Philosophy

The ability to make sense of a wide array of stimuli presupposes the human tendency to organize information in a meaningful way. Efforts to assess the degree to which students organize information meaningfully have been hampered by several factors including the idiosyncratic way in which individuals represent their knowledge either with words or visually. Concept maps have been used as tools by researchers and educators alike to assist students in understanding the conceptual interrelationships within a subject domain. One concept-map assessment in particular known as the construct-a-map task has shown great promise in facilitating reliable and valid inferences from student concept-map ratings. With all of its promise, however, the construct-a-map task is burdened with several rating difficulties. One challenge in particular is that no published rubric has been developed that accounts for the degree to which individual propositions are important to an understanding of the overall topic or theme of the map. This study represents an attempt to

examine the psychometric properties of two construct-a-map tasks designed to overcome in part this rating difficulty.

The reliability of the concept-map ratings was calculated using a person-by-rater-by-occasion fully crossed design. This design made it possible to use generalizability theory to identify and estimate the variance in the ratings contributed by the three factors mentioned, the interaction effects, and unexplained error. The criterion validity of the concept-map ratings was examined by computing Pearson correlations between concept-map and essay ratings and concept-map and interview transcript ratings.

The generalizability coefficients for student mean ratings were moderate to very high: .73 and .94 for the first concept-mapping task and .74 and .87 for the second concept-mapping task. A relatively large percentage of the rating variability was contributed by the object of measurement. Both tasks correlated highly with essay and interview ratings: .62 to .81.

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CHAPTER 1: INTRODUCTION

Dissatisfaction with traditional forms of assessment has led many educators to seek alternative ways to reliably and validly assess student conceptual understanding. Many traditional assessments such as multiple choice, alternative response, matching, short answer, and so on can be reliably scored but often test recall or recognition of facts without regard to how students organize these facts or concepts within a larger conceptual framework (Ruiz-Primo & Shavelson, 1996).

Those assessments that have the potential to measure the degree of student conceptual-framework organization, such as essays or interviews, can be time consuming to administer and to evaluate (Brussow, 2004). Concept maps provide an alternative to these traditional assessments.

Concept Maps

While concepts maps have been recommended as a useful means of assessing student-organized understanding, they have generally been used more for instructional rather than for assessment purposes. Ruiz-Primo, Shavelson, Li, and Schultz (2001) state that concept maps "follow from the notion that concept interrelatedness is an essential property of knowledge" (p. 101). They go on to explain that concept maps also follow from the notion that concept interrelatedness is likewise an important aspect of competence in a domain or discipline.

A concept map is a graphic representation intended to reveal a student's understanding of how the concepts within a content domain are interrelated. An example of a concept map is shown in Figure 1. Since concept mapping was first introduced by Joseph D. Novak and his colleagues during the 1970s a consensus has evolved among educational researchers concerning basic conventions used to construct concept maps. These conventions consist of four key components (a) nodes, (b) links, (c) linking words or phrases, and (d) propositions. These four components are described in greater detail in Table 1.

Instructors have used concept maps to promote understanding by helping individual students to (a) organize their knowledge, (b) make explicit connections between concepts, (c) clarify the meaning of the relationship between various pairs of concepts, and (d) recognize how individual concepts fit together into a larger,

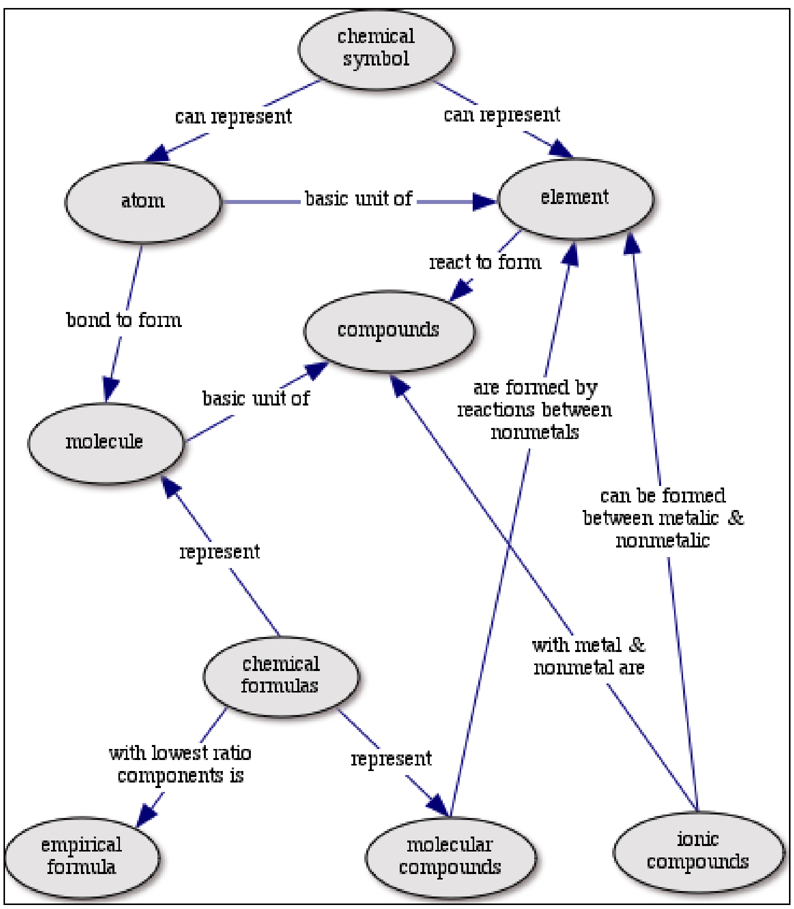


Figure 1. Example of a concept map.

Note. Excerpted from Francisco, Nakhleh, Nurrenbern, and Miller (2002).

Table 1

Four Main Components of Concept Maps

Component	Description
Nodes	Ellipses that each represent a different concept
Links	Lines that connect various nodes
Linking phrases	A label for each line that briefly describes the relationship between the linked concepts
Proposition	The combination of any two nodes and the label that connects them is a proposition. These propositions are the basic unit of meaning in a concept map.

interdependent network or conceptual framework.

The major advantage of concept maps is that they provide a means of eliciting a tangible representation of the conceptual framework within a student's mind. Presumably such maps manifest the structure and organization of the student's mental map so that others can observe it and assess it in terms of completeness and accuracy of the propositions posited.

The Problem

Many educational researchers have asserted that student concept-mapping scores have the potential of providing evidence of how well student knowledge is organized (Liu & Hinchey, 1996; Mintzes, Wanderseee, & Novak, 1998; Novak & Gowin, 1984; Ruiz-Primo, Li, Yin, Shavelson, & Vanides, 2004; Wallace & Mintzes, 1990; White & Gunstone, 1992). It is important to note, however, that the map drawn by an individual may or may not correspond to or adequately represent the individual's conceptual framework (Ruiz-Primo & Shavelson, 1996). Hence, inferences drawn from the map may lack validity. In addition, the use of concept maps for assessment purposes presupposes that the maps can be reliably scored and evaluated. The main problem is the lack of evidence about the reliability and validity of the concept-map scores.

For concept maps to be viable as assessment tools, they must provide satisfactory evidence that the ratings they generate are reliable and valid (Yin & Shavelson, 2004). Rice, Ryan, and Samson (1998) reaffirmed the need to validate scores produced from student concept maps.

> If concept maps are to be used with confidence as valid measures of student achievement in support of classroom instruction, it is essential that scoring methods be developed and validated that result in scores that reflect a stronger relationship between concept maps and student learning in science, scores that are reliable measures of intended learning outcomes. (p. 1104)

A relatively small amount of empirical research regarding reliability and validity of concept-mapping scores has been conducted. The paucity of data has been occasioned by the inherent difficulty of scoring concept-map assessments (Regis & Pier, 1996; Stuart, 1985). An overarching challenge in scoring concept maps lies in the idiosyncratic nature of each student map. Because of the high degree of student-to-student variability in the way they construct concept maps, it is difficult to develop a scoring scheme that generates reliable and valid ratings (Kinchin, 2000).

Even with such obstacles, researchers continue to assert that concept-mapping scores have the potential of offering an indicator of how well student knowledge is organized (Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005, Rye & Rubba, 2002;

Nicoll, Francisco, & Nakhleh, 2001). Such assumptions must continue to be supported through empirical efforts for concept-mapping assessments to be eventually viewed as defensible measures of student-organized understanding.

The way in which each component of a concept-map assessment is designed has been shown to impact the reliability and validity of student concept-mapping scores, including (a) the type of concept-mapping task presented, which may impose constraints on the students' mapping activities (Ruiz-Primo et al., 2001; Yin et al., 2005) (b) the mode through which students produce the map (paper and pencil, or computer) (Baker, Niemi, Novak, & Herl, 1991; Fisher, 1990; Liu, 2002), and (c) the scoring method used to evaluate the map (Nicoll et al., 2001; Rice et al., 1998; Rye & Ruba, 2002).

This study focused on the first and third of these three components: the mapping task and the scoring method. The constraints each of these components place on students and raters impact claims of reliability and validity. In the case of the concept-mapping task, the fewer the constraints placed on the student the more likely the student maps will evidence a higher degree of validity than those tasks that impose more constraints.

However, the freedom afforded students in constructing such concept maps makes them challenging to score, which negatively impacts the reliability of the ratings. Several concept-mapping tasks have been designed in an attempt to reliably and validly account for student concept-mapping variability (Nicol et al., 2001; Novak & Gowin, 1984; Rice et al., 1998; Ruiz-Primo & Shavelson, 1997). One type of concept-map assessment in particular that has shown promise in reliably and validly reflecting learners' conceptual frameworks is called the construct-a-map task or "C-mapping task" (Ruiz-Primo, Schultz, Li, & Shavelson, 2001). With all of its promise, scoring the C-mapping task is burdened with a few rating difficulties. One fundamental problem is that most rubrics used with the C-mapping task have been designed to rate only the accuracy and completeness of the links in students' maps. By focusing only on these two rating elements, less kowledgeable students have been shown to receive higher ratings than more knowledgeable students (Kinchin, 2000; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005).

Solution

Researchers have considered another rating element as a means to overcome this difficulty: proposition choice (Yin et al., 2005) or importance. Proposition choice focuses the attention of the rater on not only link accuracy or completeness but also on the importance of that link in understanding the overall topic of the map. Currently, no published rubric has been shown to account effectively for proposition choice.

Statement of the Purpose

The purpose of this study was to analyze reliability and validity of two slightly different C-mapping tasks designed to account for proposition choice along with the accuracy, completeness, and relevance of each linking phrase.

Research Questions

The specific research questions are as follows:

1. What percentage of the variability in the ratings for each of the two construct-a-map tasks is due to dependable differences in the students' ability to construct important, accurate, complete, and relevant conceptual interrelationships (this represents desirable variance) and what percentage is due to one or more of the following sources of measurement error:

a. inconsistencies between raters,

b. inconsistencies across rating occasions,

c. inconsistencies described by the 3 two-way interactions that can be estimated from the two-facet, fully crossed design,

d. unexplained error that cannot be attributed to any of the identified sources?

2. How does the reliability of the mean ratings of student's conceptual understanding generated by one rater on one occasion compare across the two scoring methods?

3. How would the reliability of the mean ratings obtained from each method be increased or decreased by varying the number of raters and rating occasions?

4. How would the reliability be affected by using a more economical design that does not necessitate having each rater rate every map on every rating occasion?

5. How successfully do the concept-map ratings distinguish between students whose essays and/or interviews show evidence of important, accurate, complete, and relevant understanding of conceptual interrelationships and those students who do not exhibit this degree of understanding?

Chapter Organization

As is the case with most educational research, researchers have the complex task of studying aspects of instruction, learning, and assessment as they interact with one another in complex human environments (Cobb, Confrey, di Sessa, Lehrer, & Schauble, 2003). These interactions are of sufficient complexity that it is difficult to construct an air-tight study that accounts a priori for all of these interacting factors. Another level of complexity was added to this study since concept-map assessments are unfamiliar to most students and educators in traditional learning environments.

With this challenge in mind the author decided to conduct a pilot study that would inform the design and implementation of the main study. The lessons learned in the pilot study and the efforts to make changes to account for these lessons learned are documented. The organization of the study proceeds as follows: Chapter 2 establishes the literary support for the foundational assumptions and theoretical framework guiding this study, chapter 3 lays out the method employed in the study, chapter 4 reports the results, and chapter 5 presents discussion points along with recommendations for future studies.

CHAPTER 2: LITERATURE REVIEW

This chapter builds a case for the use of concept maps in assessing student conceptual frameworks by providing a review of the construct concept maps are designed to target and by highlighting various concept-mapping assessment topics. These topics include (a) the historical development of concept-map assessments, (b) a framework outlining concept-map assessment component parts, and (c) the psychometric properties of concept-map assessment ratings. A rationale is then laid out as to how the current study draws on and contributes to the concept-mapping assessment literature.

The Construct of a Person's Conceptual Framework

A rationale for the construct of students' conceptual frameworks that concept maps supposedly target is considered in this section. Working definitions and instances of what constitutes a concept and a conceptual framework are presented along with a description of the degree of importance contemporary educational researchers place on organized understanding as it relates to the acquisition of knowledge.

Concepts

A *concept* is a mental representation of a category (Anglin, 1977; Howard, 1987; Klausmeier, 1990, 1992; Medin & Smith, 1984; Merrill & Tennyson, 1977; Murphy, 2002; Smith & Medin, 1981; Tennyson & Park, 1980). The category referenced by a concept may be a set of any of the following:

1. Objects that share some common characteristics (e.g., chemicals, clothing, enthymemes, euphemisms, gravel, idioms, islands, medicines, metaphors, myths, parables, planets, poetry, polygons, proteins, sheep, syllogisms, vehicles, and vitamins)

2. Events (e.g., earthquakes, elections, experiments, explosions, floods, games, wars, accidents, holidays, recesses, robberies, hunting seasons, or filing deadlines)
3. Actions or activities (e.g., singing, dancing, bluffing, joking, filibustering, voting, washing, mocking, paraphrasing, plagiarizing, procrastinating, questioning, or teasing)
4. Processes (e.g., digestion, photosynthesis, oxidation, evaporation, long division hypothesis testing, judicial review, gerrymandering, and oblique factor rotation)
5. Roles (e.g., teacher, principal, plaintiff, defendant, referee, legislator, mediator victim, partner, predator, supervisor, employer, tourist, or immigrant)
6. Relationships (e.g., above, behind, close, next to, inside of, shorter than, equal to, cousin, uncle, spouse, grandparent, dependent clause, subordinating conjunction, and covariate)
7. Situations or conditions (e.g., wet, frozen, empty, inert, asleep, sick, unemployed, bankrupt, incarcerated, monopoly, recession, retired, dictatorship, democracy, or anarchy)
8. Hypothetical constructs (e.g., atoms, electrons, genes, imaginary numbers, sampling error, standard error of the mean, achievement motivation, curiosity, hypocrisy, and inferiority complex).

Categories

The types of categories listed above overlap somewhat. Hence, some concepts listed as activities may also be processes, some roles may also be relationships, and some relationships may also be situations or conditions. Nevertheless, these eight types illustrate the point that the concept of a *concept* includes a broad range of different types.

Some concepts are very abstract (e.g., imaginary numbers or standard error of measurement), while others are more concrete (e.g., sedimentary rocks). Some concepts refer to categories that are clearly and precisely defined (e.g., isosceles triangle, iambic pentameter, clef, and tetrachord), while others refer to categories that are more vaguely defined (e.g., art, jazz, music, poetry, or politicians). Concepts are ideas that exist in the minds of individual people and thus are at least somewhat idiosyncratic and personal (Carroll, 1964; Howard, 1987). Consequently, what one person considers *music* might well be classified as *noise* by someone else, and an action classified as *criminal* by one person may be considered *legal* by another. Similarly, what some individuals would classify as a *bargain* may be considered as a *cheap imitation* by others.

Howard (1987) emphasized that "A category is distinct from a concept" (p. 4). Concepts are mental abstractions in the minds of people, whereas categories consist of instances of external stimuli (objects, events, actions, activities, processes, situations, etc.) that an individual classifies as members of some specified set. Hence, the category is not the concept, but rather the set of instances to which the concept refers. For example, the concept *clothing* includes a broad range of instances of skirts, shirts, blouses, dresses, pants, socks, shoes, coats, hats, belts, ties, and underwear, etc. Instances of this category exist independently of the mind, but the concept *clothing* is a mental abstraction that does not have an existence outside of the mind. Furthermore, the word used to refer to a concept is not the concept but simply the name or label used to identify or represent that category (Carroll, 1964).

In addition, an individual member of a class or group is not the concept, but a single instance of that concept. Regardless of the particular concept being considered, the members of that category are presumed to share sufficient similarities to warrant classifying them as ostensibly equivalent in spite of their uniqueness and differences. As explained by Bruner, Goodnow, and Austin (1956), “to categorize is to render discriminably different things [as if they were] equivalent, to group the objects and events around us into classes, and to respond to them in terms of their class membership rather than their uniqueness” (p. 1).

People start learning concepts from the time they are babies and continue clarifying, refining, and extending these concepts and learning additional concepts throughout their lives. Much of formal schooling is devoted to helping students identify and revise misconceptions they may have developed and helping them to acquire new concepts.

One advantage of the ability to categorize objects, events, processes, and situations, etc. by using concepts is the cognitive economy that it provides an individual (Rosch, 1978). Without this ability, Bruner et al. (1956) assert that humans would be “slaves to the particular” (p. 1) and unable to cope with the broad diversity of their everyday experience. Medin and Ross (1992) elaborated on this idea in the following statement:

> Without categories we would be unable to make any sense of our experience or to profit from it. If each thing we encountered was totally unique and unlike anything else we had ever known, we would not know how to react to it or make any useful predictions about its properties. We would be literally lost in a sea of new experiences, helpless to employ any of our prior knowledge to navigate. (p. 362)

Another advantage of concepts is that they provide individuals with ideas to think with as they engage in categorical reasoning, rule using, problem solving, predicting future events, and many other forms of thinking (Klausmeier, 1992). A third advantage of concepts is that persons who have acquired some basic concepts are able to use those already acquired concepts to learn new concepts. For instance, a student who does not understand the concepts *variance* and *matrix* is unlikely to understand the concept of an *eigenvalue*. But a student who already understands variance and matrix can readily learn what an eigenvalue is.

Conceptual Framework

Concepts generally do not exist in isolation (Jahnke & Nowaczyk, 1998; Lawson, 1995). Rather, they typically exist in clusters, networks, or systems of interrelated concepts that are organized in some manner. Howard (1987) declared that "All the concepts a person knows ultimately connect to each other in a maze of taxonomies, partonomies and other structures. All this knowledge constitutes a person's *cognitive structure*" (p. 11; italics in original).

Other psychologists and cognitive scientists have used the term *cognitive structure* to refer to the manner in which knowledge may be represented in the mind of the knower (Ausubel, 1963). This term refers more to a virtual structure rather than to a physical configuration. The use of cognitive structure is not meant to suggest that some sort of physiological edifice actually exists in people's minds. What it is meant to suggest is that the process of learning new concepts involves relating them to previously acquired concepts, making connections between the new concepts, and organizing the set by linking them together in an integrated manner. This helps the learner understand the nature of the various relationships and how the various components fit together into a meaningful whole (Ausubel, 1968). Some researchers refer to such clusters of interrelated concepts as schema or schemata. Others describe them as conceptual frameworks or semantic networks (Fisher, 2000). Regardless of the label used, these cognitive structures are not directly observable and their existence can only be inferred.

Contemporary Importance

As evidence of how fundamental the construct of organized understanding or knowledge is viewed by foremost educational researchers in the United States, several conclusions regarding its importance are cited here as reported in the book *How People Learn* (Bransford, Brown, & Cocking, 2000). This work, published by the National Research Council (NRC), reports the work of two committees organized by the NRC to find ways of improving instruction in schools by more closely linking classroom practice to the findings of research about how humans learn. The two committees included (a) the Commitee on Developments in the Science of Learning, and (b) the Committee on Learning Research and Educational Practice. The first committee focused on the results of research about the nature of human learning and how it occurs. Based on the work of the first committee, the second committee formulated recommendations for changing classroom practice to more closely conform to the findings of research regarding factors that facilitate learning. In the next-to-the last chapter, the editors cite numerous conclusions reached by the two committees. Four of these conclusions are cited below:

1. “Learning with understanding is more likely to promote transfer than simply memorizing information from a text or a lecture” (p. 236).

2. “Transfer and wide application of learning are most likely to occur when learners achieve an organized and coherent understanding of the material” (p. 238).

3. “Effective comprehension and thinking require a coherent understanding of the organizing principles in any subject matter” (p. 238).

4. “Different domains of knowledge, such as science, mathematics, and history, have different organizing properties. It follows, therefore, that to have an in depth grasp of an area requires knowledge about both the content of the subject and the broader organization of the subject” (pp. 237-238).

The first of these four conclusions refers to advantages that learners are presumed to obtain if they acquire understanding. The last three conclusions all make reference to the idea that understanding includes knowledge that is organized in some meaningful manner.

History of Concept-Map Assessment

With this theoretical foundation in mind, the section that follows focuses on the history of concept-map assessments and the rationale for their use in tapping the construct or trait of organized knowledge.

In the early 1970s Joseph Novak and his colleagues pursued questions regarding children’s acquisition and use of scientific concepts. In the course of their efforts, they became dissatisfied with how functionally limiting traditional test questions, such as multiple-choice and short-answer test items, were in validly measuring student knowledge. They found that student responses to these traditional items in many instances demonstrated little correspondence between the correct answers the students selected and the meaning they expressed in subsequent interviews (Novak & Gowin, 1984).

As they considered the process by which young children acquire concepts, it became increasingly apparent that children acquire an understanding of concepts by degrees. For example, a child's concept of a *dog* at first may have an exclusive relationship with the concept *four legs*. The resulting *propositional link* (an expression describing the relationship between two concepts) would read *dogs have four legs*. Based on this conceptual connection, when a child sees other four-legged creatures such as a *cow* or a *horse*, he or she may mistakenly call them a dog. Over time, however, relationships are established between the concept dog and other unique concepts such as *bark* or *fetch*, while at the same time these new concepts are noted to have no relationship with the concept cow or horse. Novak's group hypothesized that children develop an understanding of the meaning of a concept by degrees as they acquire "a growing set of propositional linkages between the concept of central concern and other related concepts" (Novak & Gowin, 1984, p. 94).

They concluded that they could not document the changes in a student's conceptual understanding over time unless they could design a way to capture those changes in a student's cognitive structure, which they asserted consists of a series of interconnected propositional links. One of Novak's former research assistants, Richard Rowell, derived concept maps from the transcripts of clinical interviews he had conducted. Once constructed, he analyzed the concept maps for meaningful linkages between related concepts (Novak & Gowin, 1984). Through this and other research efforts concept maps began to be used not only as instructional but also as evaluative tools. Since that time research has continued through the last thirty years examining various uses of concept-map assessments as a measure of a student's conceptual framework.

Components of Concept-Map Assessments

From the 1980s on into the 1990s concept-map assessment research dealt with challenges related mostly to the reliability and to a much lesser extent the case for validity of student concept-map ratings. Ruiz-Primo and Shavelson (1996) conceptualized a framework that decomposed concept-map assessments into discrete and overlapping component parts. This framework characterizes a concept map-assessment as "(a) a task that invites students to provide evidence bearing on their knowledge structure in a domain, (b) a format for the students' response, and (c) scoring system by which students' concept maps can be evaluated accurately and consistently" (p. 573).

Ruiz-Primo and Shavelson (1996) claimed that without any one of these three components a concept-map assessment could not be considered an assessment. This framework has served as a guide for many researchers since its inception, including work done by Jacobs-Lawson (2001), McClure, Sonak, and Suen (1999), Rice et al. (1998), Rye and Rubba (2002), West, Park, Pomeroy, and Sandoval (2002), Yin et al. (2005), etc.

In the section that follows, each concept-mapping assessment component from this framework is defined and illustrated. Studies where research questions have dealt with one or multiple aspects of these components are described as well. This section draws heavily on work done by Ruiz-Primo and Shavelson (1996).

Task

The first component of a concept-map assessment is a task that invites students to provide evidence of their knowledge structure in a domain. According to Ruiz-Primo and Shavelson (1996), a concept-mapping assessment task is composed of three variables: task demands, task constraints, and content structures. All variations stemming from these three elements could produce over a thousand different concept-map assessments.

Task Demands

A task demand constitutes the demand placed on students in constructing their concept maps. For example, a student may be directed to construct a map from scratch, meaning they are given a blank piece of paper and a main topic and asked to connect all of the key concepts subsumed under that topic. Such a task would be more cognitively demanding compared to other tasks where more prompts are presented (Lomask, Baron, Greig, & Harrison, 1992). Students may be directed to sort a series of words representing concepts on cards based on the strength of their conceptual association or demonstrate the hierarchical structure of concepts with most inclusive at the top and least inclusive at the bottom (White & Gunstone, 1992). The task is more or less demanding based on the degree to which the activity taxes students working memory.

The nature of the task demands has implications for many aspects of concept-map assessing activities including feasibility of administration and analysis as well as the reliability and validity of the resulting ratings. For example, if concept maps are to be used feasibly for large-scale assessment either a way would need to be devised to machine score them or resources expended to hire raters to rate them. Cognizant of this issue Ruiz-Primo et al. (2001) compared two mapping tasks, the first to be scored by machine and the second requiring rater-mediated scoring, to see if they were equivalent. Unfortunately for those looking to use concept-map assessments in large-scale testing, they found that the automated scores in many instances were more an artifact of students' ability to strategize (i.e., process of elimination) than their understanding of how the concepts were interrelated. The task demands imposed by these two mapping tasks were found to be different. The authors hypothesized that different prompts and directions provided in each task caused students to draw upon different cognitive processes.

Few studies have been conducted studying the impact of task demands on the reliability and validity of concept-map assessments. Those studies that have been conducted include the comparison of two concept-mapping tasks (Yin et al., 2005; Ruiz-Primo et al., 2004; Ruiz-Primo et al., 2001), and hierarchical versus nonhierarchical concept-mapping task directions (Ruiz-Primo et al., 1997).

Task Constraints

Task constraints refer to the restrictiveness of the task. For example, a task that directs students to construct a hierarchical map would be more restrictive than a task that provides students the freedom to choose between constructing a hierarchical and a nonhierarchical map. As another example, a task that provides linking phrases is more restrictive than a task that directs students to create their own linking phrases.

On the surface it may appear that task constraints and task demands are essentially the same. However, task constraints may or may not be impacted by the nature of the task demands. In some instances they may have an inverse relationship. One mapping task may be more restrictive and less demanding at the same time. A task that directs students to construct a map from a topic would be less restrictive and more demanding than a task that directs students to construct a map from a list of concepts. In other instances the degree of restrictiveness and task demands may be highly correlated. For example, in the study conducted by Ruiz-Primo et al. (2001) cited earlier, one might expect the automated-scoring technique, while more restrictive, to be less demanding than the rater-mediated mapping task. However, researchers found that students tended to take time to monitor their answers more carefully on the more restrictive task than the less restrictive task. With the restrictive task students tended to engage in a trial-and-error process not engaged in with the less restrictive task.

Content Structures

According to Ruiz-Primo and Shavelson (1996), "Task content structures refers to the intersection of the task demands and constraints with the structure of the subject domain to be mapped" (p. 578). For example, if the content domain is hierarchical in nature, then students may be directed to construct a hierarchical map (Figure 2). If the content is more procedural in nature the students may be directed to construct a chain map (like a flow chart with linking phrases as depicted in Figure 3) (Yin et al., 2005). If the concepts in a given content domain are more ambiguous, students may be directed to construct several maps with the same list of concepts in light of varying contexts.

Ruiz-Primo et al. (1997) compared the impact of imposing instructions that directed students to construct a map of (a) a list of hierarchically related concepts hierarchically, (b) a list of hierarchically related concepts nonhierarchically, (c) a list of nonhierarchically related concepts nonhierarchically and finally (d) a list of nonhierarchcially related concepts hierarchically. Their intent was to assess the degree to which the imposition of structure on students' representations interact with the structure of the subject domain mapped. Their findings were inconclusive due to the challenge of scoring what they termed "the hierarchiness" (p. 20) or hierarchical features of student maps. However, the study they conducted demonstrated their intent to investigate the way in which content structures interact with task demands and constraints.

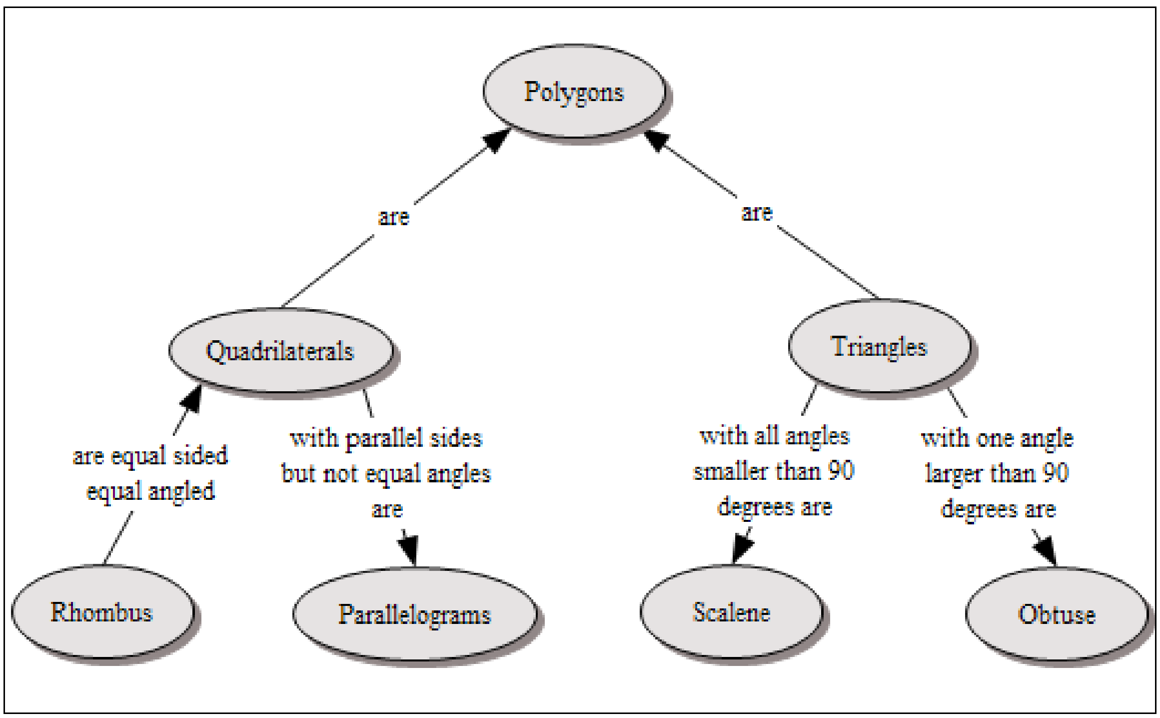


Figure 2. Example of a hierarchical map.

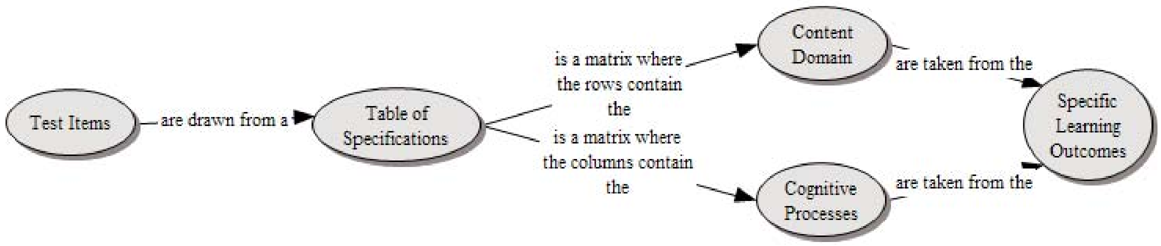


Figure 3. Example of a chain map.

The selection of concepts used in the mapping task can likewise impact both the restrictiveness and demands placed on the student. For example, a list of concepts that are highly related will pose different demands and constraints on student responses than a list of loosely associated concepts.

A strong conceptual relationship between a pair of concepts is present when two concepts share an unambiguous, direct relationship. For example the concept *translation process* has a strong association with the concept *proteins*. Proteins are synthesized through the translation process. Notice that only the concept *synthesis* was required to make the connection between these two concepts. An unambiguous direct connection is one of the key properties of a strong relationship between two concepts.

On the other hand, a loosely associated pair of concepts requires the use of other concepts to construct a meaningful relationship. For example, the concept *tRNA* and proteins have an indirect connection that requires the use of several concepts to describe their relationship. tRNA is a molecule that brings the amino acids to the ribosomes. On one end of the tRNA molecule is attached the amino acid and on the opposite end is attached what is called an anti-codon. As the tRNA molecule brings the amino acid to the ribosomes its anti-codon matches with a codon on an mRNA molecule. This entire process, known as translation, makes possible the synthesis of proteins. If a concept-mapping task has a list of concepts that possess the same weak conceptual interrelationship as tRNA and proteins than the task demands may make completing the assignment untenable, because mapping conventions require students to connect those concepts with the most direct relationships.

Response Format

The second component of a concept-map assessment in this framework is a format for student responses. Response format refers to the format or medium by which a student responds to the concept-mapping task. For example, a student may provide an oral explanation producing a transcription from which a concept map is constructed, draw a map with paper and pencil or construct it electronically with concept-map-generating software. Ruiz-Primo & Shavelson (1996) identified three aspects of a response format from which variations of responses could be derived: "(a) the *response mode*, (b) the *characteristics of the response format*, and (c) the *mapper*" (p. 579; italics in original).

Response Mode

The response mode refers basically to the medium by which the map is drawn, whether with paper and pencil, computer generated, card sorting etc. For example, Yin et al. (2005) gave students nine sticky notes with the names of nine related concepts written on them. Students were directed to organize the sticky notes by placing them on a blank sheet of paper. They were then directed to draw lines between the sticky notes. The researchers believed that this would help facilitate greater ease at redrawing or reconfiguring the map during the course of the assessment. In another study, Liu (2002) found that students reported great satisfaction with their concept mapping experience when they were able to map a list of concepts using computer software designed to facilitate the mapping process.

Response Characteristics

A concept-map assessment consists of the directions given to the students and the format characteristics within which the students respond. Response format characteristics are tied closely with the task demands and constraints imposed by the assessment. What follows are a series of examples of task instructions with their corresponding format characteristics:

1. Select-the-link (Figure 4).
2. Select-the-node (Figure 5).
3. Select-the-link and node (Figure 6).
4. Fill-in-the-link (Figure 7).
5. Fill-in-the node (Figure 8).
6. Fill-in-the link and node (Figure 9).
7. Construct-a-map by assembling concepts and linking phrases (Figure 10).
8. Construct-a-map with a list of concepts provided (Figure 11).
9. Construct-a-map from scratch (Figure 12).
10. Construct-a-hierarchical-map (Figure 13).

Several studies have been conducted analyzing the impact of response format characteristic on assessment reliability, validity, and feasibility. These include a study of fill-in-the link and node concept-map assessments (see Figure 9) (e.g., Anderson & Huang, 1989; McClure & Bell, 1990; Schau & Mattern, 1997), construct-a-map with a

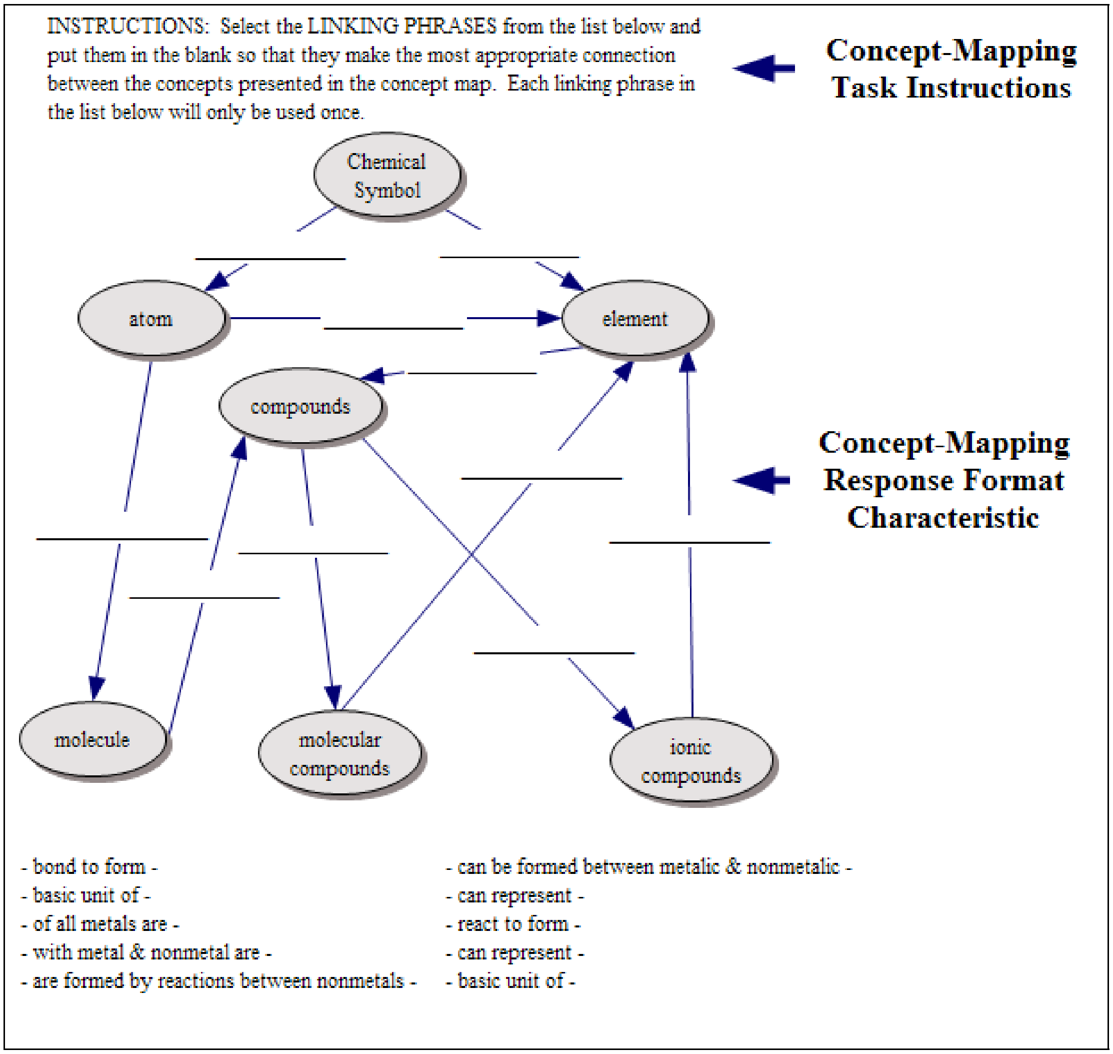


Figure 4. Select-the-link assessment.

Note. Adapted from Francisco et al. (2002).

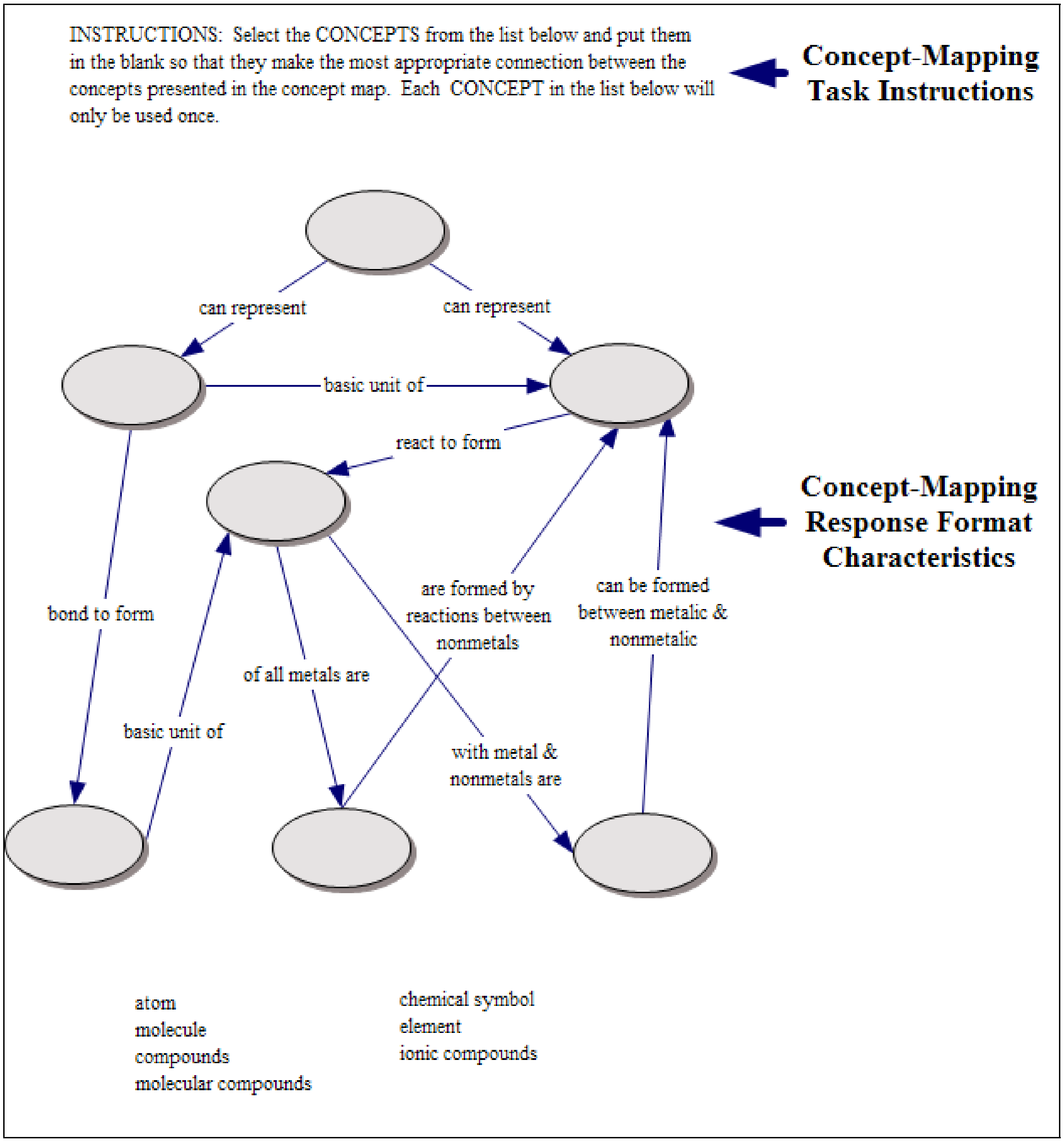


Figure 5. Select-the-node assessment.

Note. Adapted from Francisco et al. (2002).

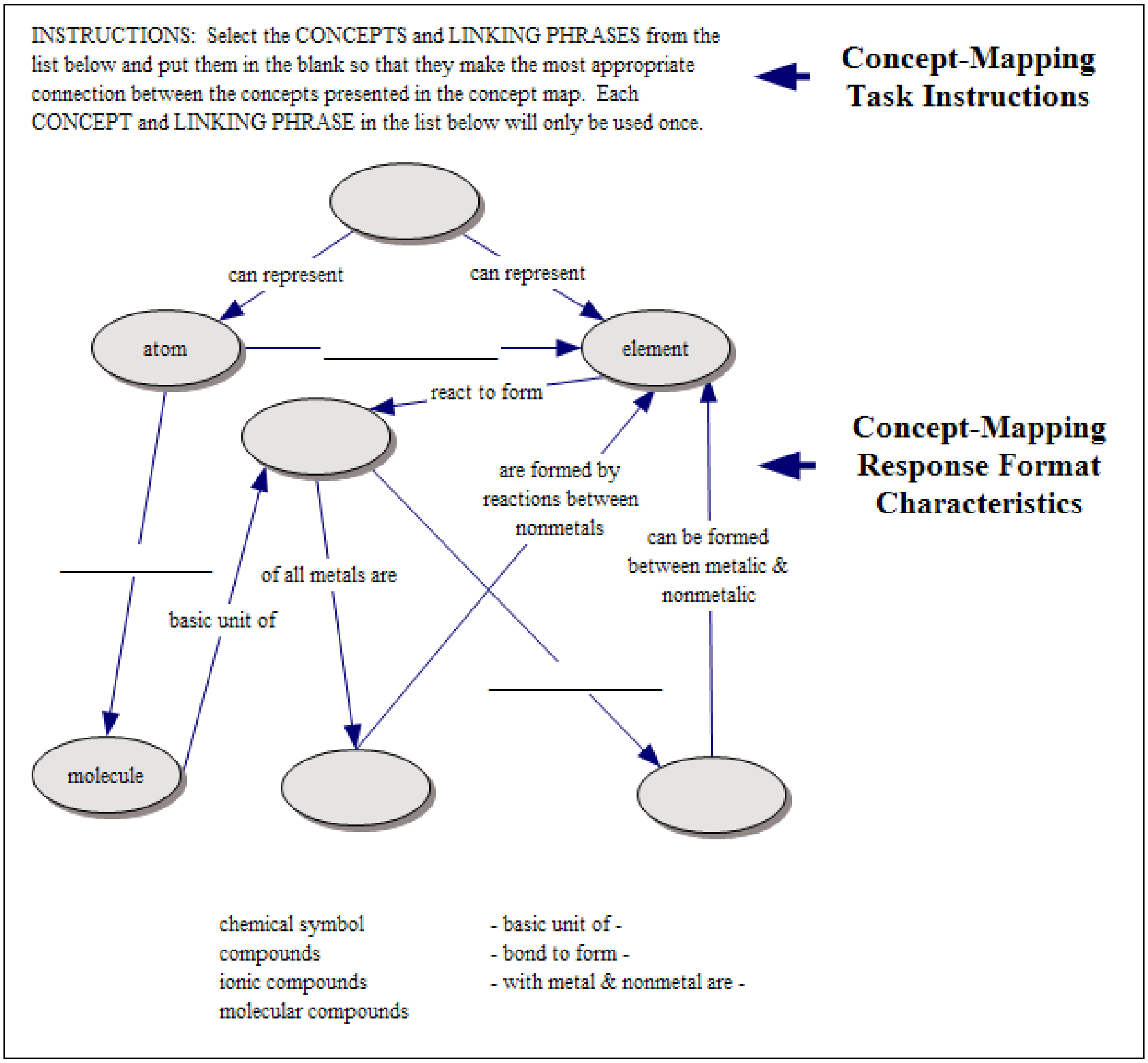


Figure 6. Select-the-link and node assessment.

Note. Adapted from Francisco et al. (2002).

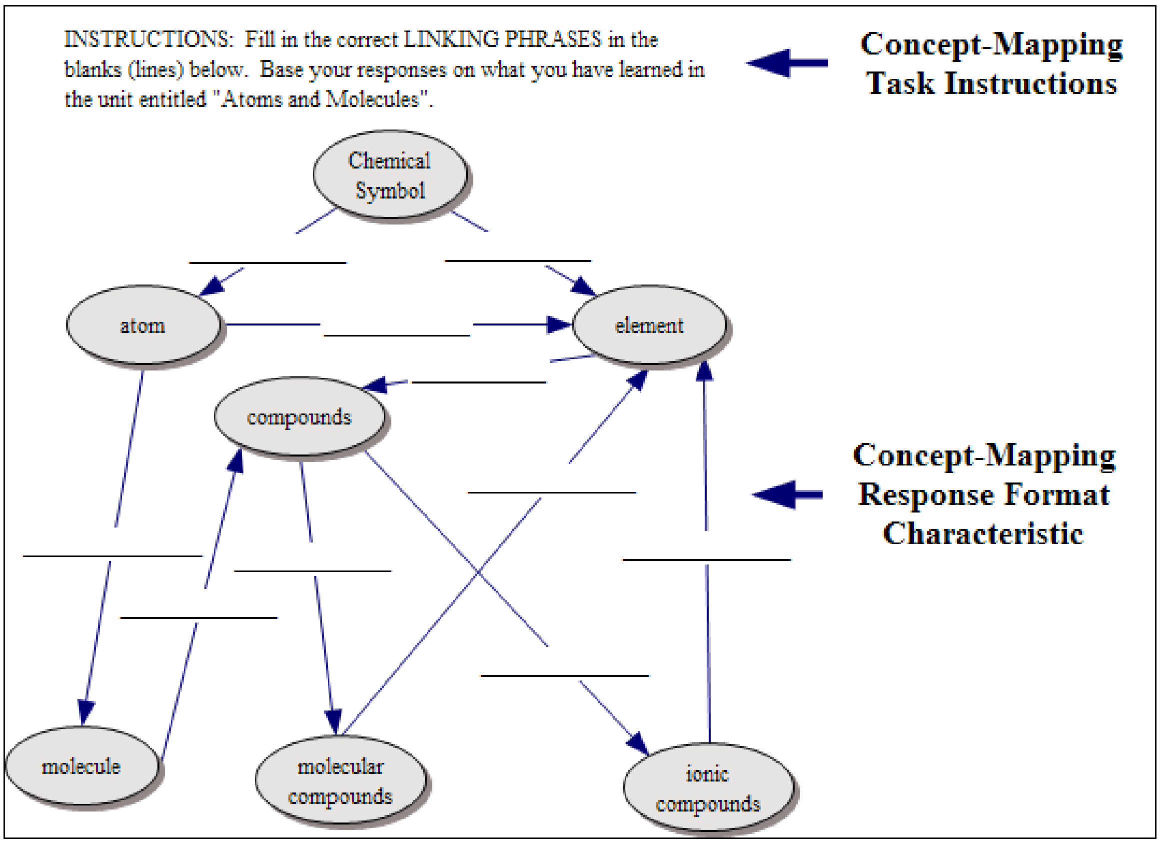


Figure 7. Fill-in-the-link assessment.

Note. Adapted from Francisco et al. (2002).

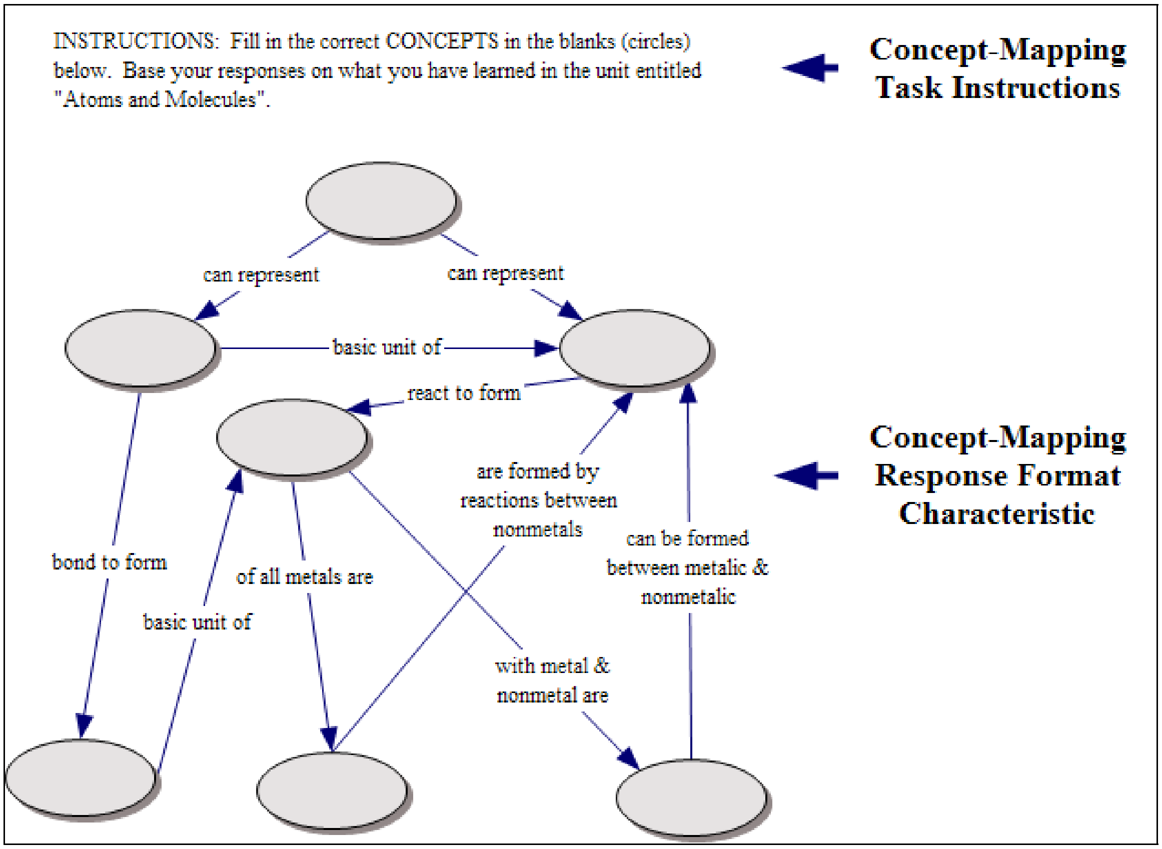


Figure 8. Fill-in-the-node assessment.

Note. Adapted from Francisco et al. (2002).

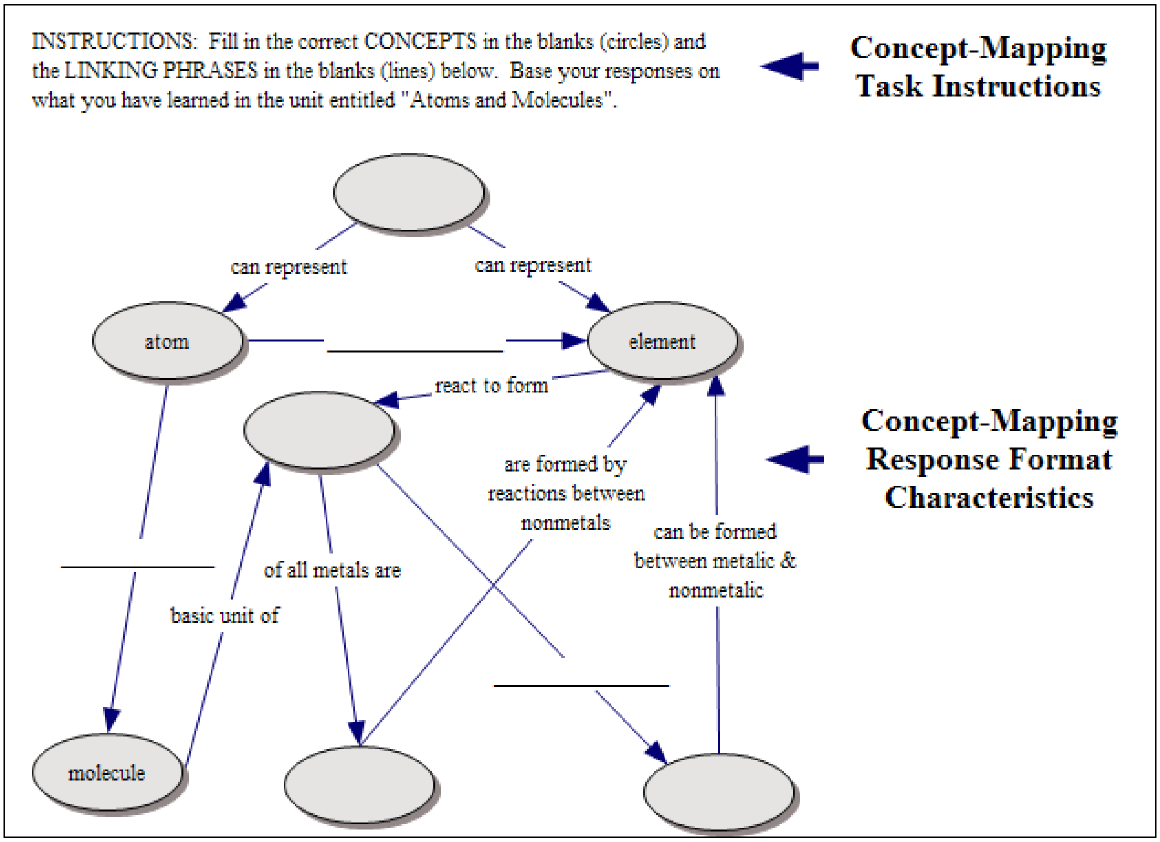
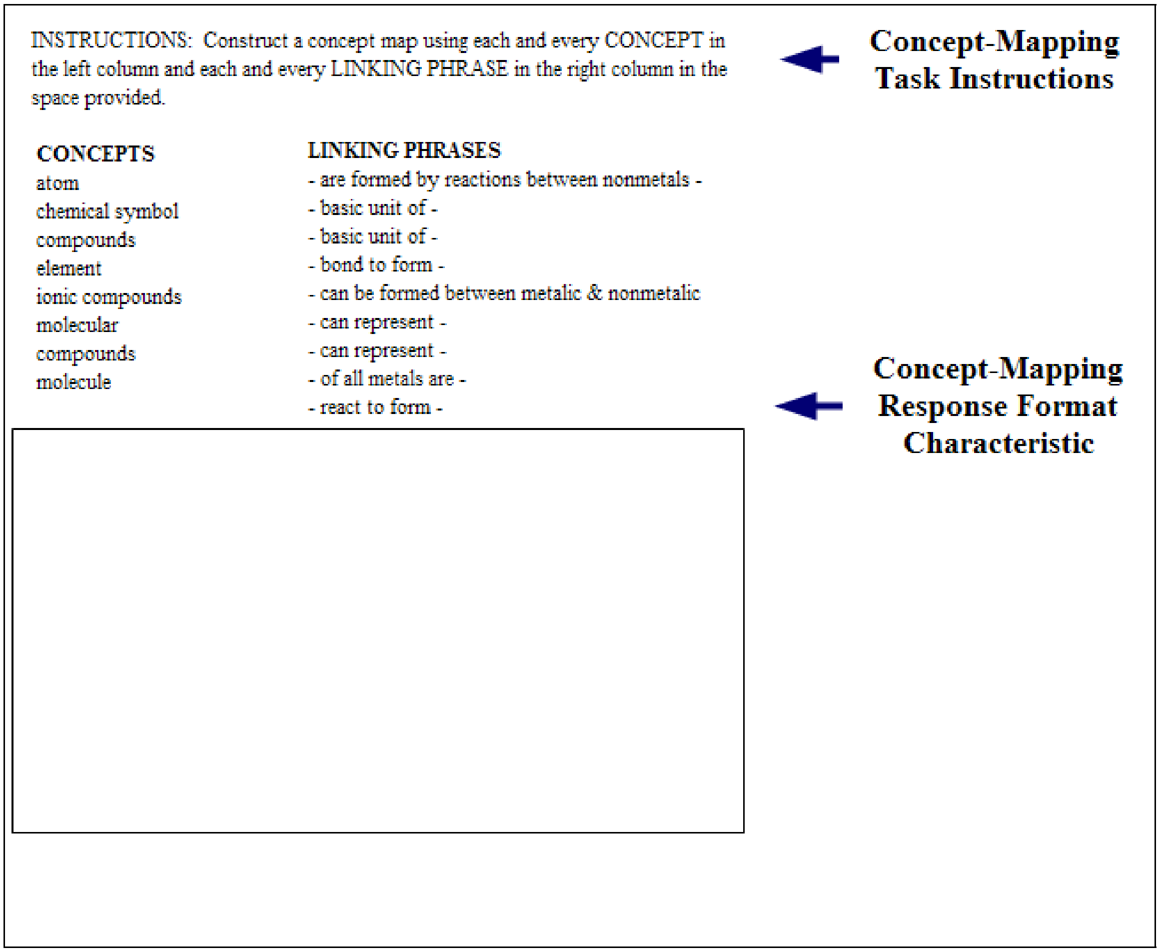


Figure 9. Fill-in-the-link and node assessment.

Note. Adapted from Francisco et al., 2002.


INSTRUCTIONS: Construct a concept map using each and every CONCEPT in the left column and each and every LINKING PHRASE in the right column in the space provided.

CONCEPTS	LINKING PHRASES
atom	- are formed by reactions between nonmetals -
chemical symbol	- basic unit of -
compounds	- basic unit of -
element	- bond to form -
ionic compounds	- can be formed between metalic & nonmetalic
molecular	- can represent -
compounds	- can represent -
molecule	- of all metals are -
	- react to form -

Figure 10. Assembling concepts and linking phrases assessment.

Note. Concepts and linking phrases taken from Francisco et al. (2002).

INSTRUCTIONS: Construct a concept map in the space below showing how ideas listed below are interrelated.

Concept-Mapping Task Instructions

- *atom*
- *chemical symbol*
- *compounds*
- *element*
- *ionic compounds*
- *molecular compounds*
- *molecule*

Concept-Mapping Response Format Characteristic

Figure 11. List of concepts provided assessment.

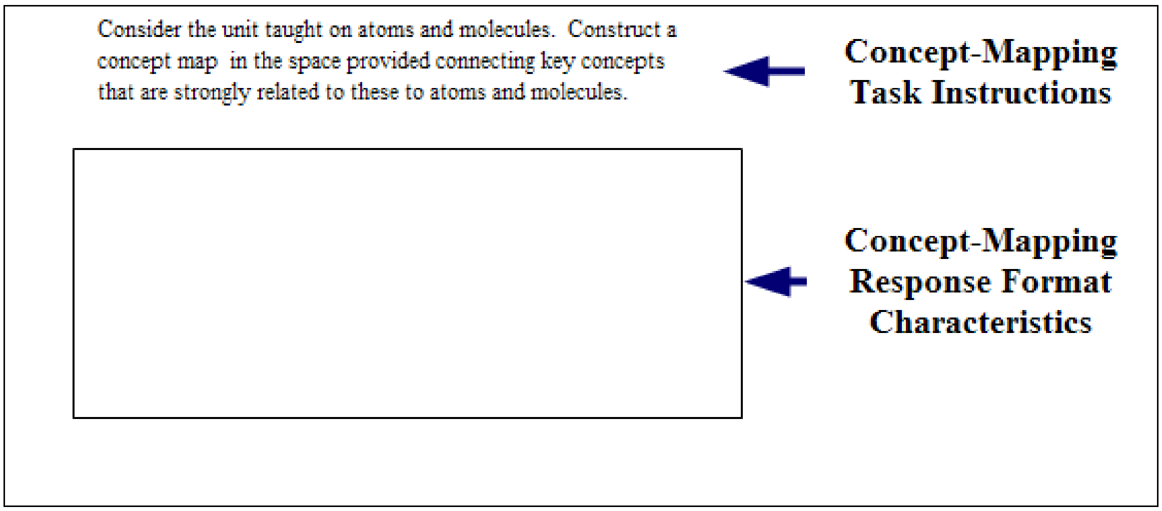


Figure 12. Construct-a-map from scratch assessment.

Examine the concepts listed below. They were selected from the chapter on Atomic Structure that you recently studied. Construct a hierarchical concept map using the terms provided below. Organize more general terms above the more specific ones. Draw a line between the terms you think are related. Label the line using phrases or only one or two words.

You can construct your map on the blank pages attached. When you finish your map check that: (1) you have all the concepts on the list in your map; (2) all the lines have labels; (3) your map is explaining atomic structure. After checking your map redraw it so someone else can read it.

Staple you final map to this page.

LIST OF CONCEPTS
atoms
atomic mass
atomic number
atomic orbitals
electrons
elements
energy levels
isotopes
mass number
negative charge
neutral charge
neutrons
nucleus
p orbitals
positive charge
protons
s orbitals

Figure 13. Construct-a-heirarchical-map.

Note. Excerpted from Ruiz-Primo et al. (1997, p. 31).

list of concepts provided (see Figure 11) (Yin et al., 2005; Ruiz-Primo et al., 2001; McClure et al., 1999), and construct-a-map by assembling concepts and linking phrases (see Figure 10) (Ruiz-Primo et al., 2001).

Of all the concept-mapping tasks, the construct-a-map with a list of concepts provided (see Figure 11) is considered to be the "gold standard of concept-map" assessments (Yin et al., 2005, p. 167). Ruiz-Primo et al. (2001) investigated the possibility of the fill-in-the-map task (see Figures 7 and 8) providing the same picture of student-connected understanding as the construct-a-map task. Their finding led them to posit that construct-a-map task scores more "accurately reflected the differences across students' knowledge structure" (p. 275) than the fill-in-the-map task scores. It is for this reason that several studies have used this task as a standard to investigate its degree of equivalence with other techniques (Ruiz-Primo et al., 2001; Yin et al., 2005) or to study other concept-map assessment components such as scoring method (McClure et al., 1999) or response format (Liu 2002).

Mapper

The mapper is the one who draws the map. Students generally draw the map; however, there are instances when the map is drawn by others. In such instances, concept maps may be generated from student essays or interview transcripts. For example, Rye and Rubba (2002) interviewed students about their understanding of chlorofluorocarbons and then constructed concept maps based on the conceptual relationships expressed by the students in the interviews. Likewise, Nicoll et al. (2001) derived concept maps from interview transcripts that documented verbal cues that otherwise would not have been picked up if the student had drawn the maps themselves.

Rice et al. (1998) explained that the age of the mapper has little impact on their ability to construct a concept map. Novak and Gowin (1984) reported that children as young as primary grades have been found adept at constructing concept maps. Because of the relative ease at which concept maps can be constructed varying abilities (e.g., Anderson & Huang, 1989) and varying learning styles (Laight, 2004) have been shown tentatively to not negatively impact students from becoming good concept mappers.

Scoring System

The third and final component of a concept-map assessment is a scoring system by which student concept maps can be evaluated accurately and consistently. Ruiz-Primo and Shavelson (1996) explain that a scoring system is a "systematic method with which students' concept maps can be evaluated accurately and consistently" (p. 581). They categorize scoring systems into three general strategies: (a) scoring the components of a map, (b) comparing the student's map with a criterion or master map, and (c) using a combination of these first two strategies. To these three we may add the holistic scoring method studied by McClure et al. (1999).

Scoring Map Components

The components of a concept map that have been scored include the (a) concepts, (b) linking phrases between concepts, (c) structural or hierarchical aspects of the map, and (d) examples that are used to illustrate concepts presented on the map.

Scoring concepts. Scoring the concepts of a map should occur only if the students rather than the assessor are directed to supply map concepts. For example, in the construct-a-map from scratch task (see Figure 12) students are given a topic and asked to construct-a-map that depicts the key concepts and propositions of that topic. In this case students are directed to supply relevant concepts to the topic and then their concept selection is scored accordingly. Because of the heavy cognitive load imposed upon students with such a task, in most cases concept selection is already done for the student and hence, not scored (see Schau & Mattern, 1997). Another task that would require the scoring of student-concept selection would be requiring the students to add relevant concepts to a list of assessor-selected concepts (e.g., Rice et al., 1998). This feature adds a level of complexity to the scoring method in that students may add an innumerable number of concepts with their resulting propositions, each of which would have to be accounted for by the raters.

Scoring propositions. When scoring propositions, two strategies are generally considered: The scoring of individual propositions and the calculation of total map proposition scores. In order to simplify the scoring process most researchers with the exception of a few (e.g., Shavelson, Laung, & Lewin, 1993), have not permitted students to run "sentences through multiple nodes" creating what have been termed "dependent propositions" (Nicol et al., 2001, p. 870). When this is permitted, raters must account not only for propositions communicating independent thoughts, but also those communicating dependent thoughts. For example, the concepts dog and *domesticated* may be linked with the phrase: *dogs can be domesticated.* The concept *wild* could be an add-on, *dogs can be domesticated unless they are wild.* The proposition *domesticated unless they are wild* does not communicate an independent thought. Sometimes it is clear to a rater the meaning of the dependent proposition and other times it is not. Since one of the purposes of concept mapping is to make explicit student connected understanding, dependent propositions in many instances require subjective judgments about implicit meanings. Hence a pair of concepts connected with a linking phrase that communicates an independent thought is considered among most researchers to constitute a proposition.

Individual propositions have generally been evaluated based on their level of correctness. In some instances the propositions are scored simply as correct or incorrect (Yin et al., 2005) and in other instances the propositions are rated based on degrees of correctness (Ruiz-Primo et al., 2001). Some scoring methods take into account proposition choice (McClure et al., 1999) and others consider the direction of the linking phrase arrow (Anderson & Huang, 1989).

At the very least a proposition is scored based on how correct or accurate it is. A correct proposition communicates simply an idea that is accepted as valid by domain or content experts in a given context. Proposition correctness is also a function of expected student ability level. For example, in a beginning high school statistics class the correct relationship between the concepts *correlation* and *covary* could read simply, *correlation shows how much two variables covary*. However, in an intermediate college statistics course a correct relationship between these same concepts may read, *correlation is a standardized measure of the degree to which two variables covary*.

Proposition choice is another proposition-scoring attribute that has been included by some researchers in the concept-mapping assessment literature (e.g., Yin et al., 2005; Rice et al., 1998). As explained previously with the concepts tRNA and proteins, when a student selects a pair of concepts to be mapped, they connect concepts that vary in degrees in their strength of association. In a prior example, the concept dog was linked with the concept bark. However, if a student linked the concept cow with the concept bark with the linking phrase *does not*, this proposition, while correct, would not reflect as strong as an association as the proposition *a dog has the ability to bark*. Propositions may be weighted based on their associated strength as well as their relevance to the overall topic. Correctly choosing pairs of concepts to form key, fundamental propositions is essentially a function of the context or topic of the domain and the level of domain expertise possessed by the mapper.

Another scoring attribute or property of individual propositions is proposition completeness (Ruiz-Primo et al., 2004)**,** which describes the degree to which the information in the proposition demonstrates a complete understanding of the relationship between two concepts. A proposition can be accurate and vary in its degree of completeness. For example, the proposition *reliability must be present in order to claim validity* is an accurate proposition; however, a more complete expression of their relationship would be, *reliability is necessary but not sufficient in order to infer validity*. Notice that the first proposition essentially communicates that reliability is a requisite of validity. The second proposition adds the idea that reliability is requisite but not the only requirement to make a claim of validity.

Researchers such as Nicol et al., (2001) have considered other scoring properties. In their studies they derived concept maps from student-interview transcripts. They rated each link based on the following:

1. Proposition utility, which is the degree to which a proposition is considered correct.
2. Proposition stability, which is the degree to which a student expresses a proposition with certainty.

3. Proposition complexity, which is the degree to which a proposition is useful in predicting or explaining a scientific phenomena or enhancing the understanding of other connections on the map.

Because of its novelty as a proposition scoring attribute, Figure 14 is offered along with an explanation to provide greater clarity as to the nature of link complexity as described by Nicol et al., 2001. Because validity is a property of the interpretations or inferences drawn from scores then by association all forms of validity including *content*, *criterion*, *predictive*, and *concurrent validity* are likewise properties of the interpretations or inferences drawn from scores. Hence, the proposition created between the concepts validity and scores has a higher degree of complexity or explanatory power than other propositions in this map. Proposition complexity was not a scoring attribute considered in this study due to certain limitations and constraints of the course, but could be considered in further studies.

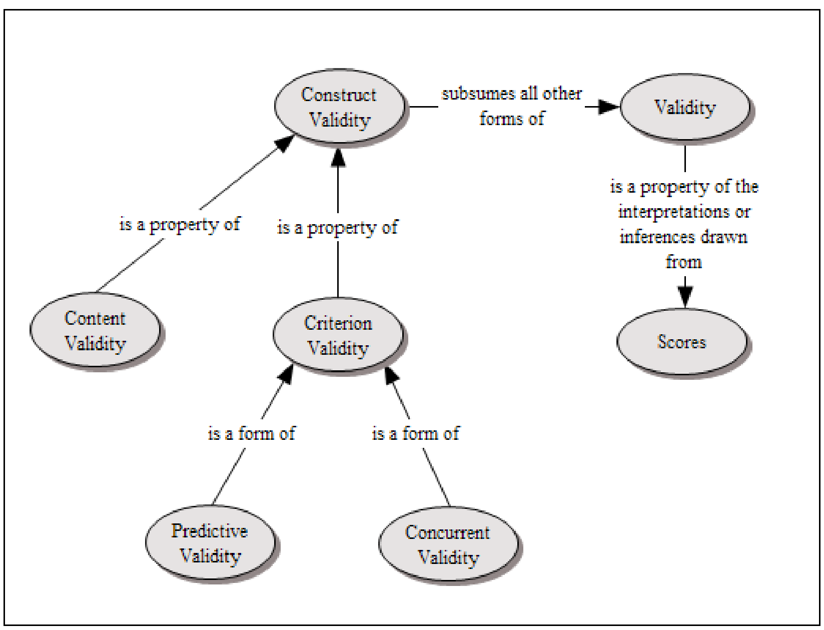


Figure 14. A concept map demonstrating link complexity.

Along with individual proposition scores, total proposition scoring schemes have also been conceptualized by researchers. Ruiz-Primo et al. (2004) describes three total proposition scores (a) total proposition accuracy – the sum of all the scored propositions in a map, (b) convergence score – the percentage or proportion of scores on a student map found on an expert or criterion map, and (c) salience score – the percentage or proportion of accurate propositions out of the total number of propositions in the student's map.

Summing the scores of all propositions in a map is a simple procedure, yet there are several issues to consider when doing so. As an extreme case, if every concept could be meaningfully connected to every other concept on a map, then the number of the total propositions that could be connected can be calculated using the formula $N(N-1) / 2$, where N equals the number of concepts in the list. If the number of concepts were 10, then the number of total possible propositions would be 45. If a student constructs 45 propositions and each proposition can be scored on a scale of 0 to 2 then the highest total proposition accuracy score would be 90.

Of course it is inconceivable that an instance could occur where every concept could be meaningfully linked with every other concept on a map. Additionally, most concepts within a given subject or discipline differ in the degree to which they meaningfully relate to one another. This scoring attribute, as described earlier, is called proposition choice or proposition importance and directs raters to give credit to students who connect those concepts that should be connected and no credit for those concepts that should not be connected. The challenge here is for content experts to develop a list of strongly associated propositions that students should make along with a list of moderately and weakly associated propositions. Such an effort can be daunting because any one discipline may possess an exhaustive list of closely and moderately related concepts. If this can be accomplished, however, then a total possible proposition score is a more viable approach to evaluate student maps (Yin et al., 2005).

Some researchers have not pursued a total proposition score because of this challenge and have looked to other scoring approaches that reflect student concept-mapping performance such as convergence and salience scores.

Convergence scores are calculated by comparing the number of propositions shared by a student map and an expert map. This score is generally calculated as a percentage or a proportion. If a student constructs 90% of the propositions found on an expert map then they would receive a .90. There are several challenges associated with using expert maps to evaluate student maps. These challenges will be identified and discussed later.

In the case of salience scores, this scoring technique is calculated in several ways (see Francisco et al., 2002; Ruiz-Primo et al., 1997). The most basic calculation is done by dividing the number of correct propositions by the total number of propositions on the map. If a student constructs ten propositions and five are correct then their score would be .5 or 50 percent correct. A challenge with salience score calculations is that a student could conceivably score a 1.0 by constructing only one or two accurate propositions. Hence a score of 1.0 may or may not represent a student who possesses a well-developed conceptual framework of the material.

Ruiz-Primo et al. (1997) compared the results of concept-mapping scores calculated using all three methods and found total proposition accuracy and convergence scores to be more consistent than salience scores. They also found that student differences were more pronounced when using total proposition accuracy and convergence scores than salience scores.

Scoring map structure. A hierarchical structure includes any structural pattern that transcends simple propositional relationships. Map structure can include subordinate /superordinate relationships between concepts as well as coordinate (coequal) relationships. Subordinate/superordinate relationships may be depicted with an all-inclusive superordinate concept placed at the top of the page and increasingly less inclusive subordinate concepts subsumed below it. For example, the concept *polygon* is a superordinate concept subsuming concepts such as *quadrilateral* and *triangle*. The concept quadrilateral in turn subsumes the concepts *rhombus* and *parallelogram* while the concept triangle subsumes the concepts, *scalene*, and *obtuse*.

Novak and Gowin (1984) designed a scoring formula that accounts for map structure by counting and weighting valid levels of hierarchy as well as cross-links connecting different clusters of strongly associated concepts. Their rationale for this was based on the assumption that expressing hierarchical levels in a given domain provides evidence of student ability to differentiate concepts based on developed nuanced understanding of how they fit into a larger conceptual framework.

However, Ruiz-Primo et al. (1997) explain that few domains are purely hierarchical, and that most manifest more or less a degree of what they term *hierarchiness*. It appears that most content domains feature some hierarchical structure; however, hierarchical relationships do not generally account for the vast number of propositional relationships (Cohen, 1983). In other words, an assertion can be made that all domains have some hierarchical skeletal structure but it generally accounts for a much smaller percentage of the total propositions that could be constructed from those domains. Scoring map structure would be important if (a) there is a strong presence of hierarchical relationships in the content domain and (b) it is the explicit objective of a course to assist students in understanding the hierarchical nature of the content.

If, however, the spatial features of the map do not account for a conceptual framework, the individual propositions would be the only map components left to score. This gives rise to the question, can the content structure of a domain be accounted for by analyzing solely the linking phrases expressed within each proposition of the map and not its spatial features? Anderson (1995) makes the following point answering this question in the affirmative:

> The spatial location of elements in a network is totally irrelevant to the interpretation. A network can be thought of as a tangle of marbles connected by strings. The marbles represent the nodes, and the strings represent the links between the nodes. The network represented on a two-dimensional page is that tangle of marbles laid out in a certain way. We try to lay the network out in a way that facilitates its understanding but any layout is possible. All that matters is what elements are connected to which, not where the components lie. (p. 148)

Constraining students' representation of their conceptual framework by imposing an ideal structure on their maps may stifle those students who require a process that is less constraining as they find the framework that best facilitates retention and understanding.

One way to capture student knowledge structure without considering the spatial layout of the map is to consider two propositional attributes: proposition choice/importance and proposition completeness. If students are to pair concepts that have hierarchical relationships, then this would be a criterion for appropriate proposition choice. If the essential relationship between two concepts is hierarchical in nature, then students would be expected to express a hierarchical relationship in the linking phrase in order for the proposition to be considered complete.

This issue has important implications for scoring concept maps. While a few researchers continue to study the possibility of scoring map structure (e.g., Yin et al., 2005) more theoretical and empirical work needs to be done considering the viability of accounting for it using methods that are reliable and valid.

Scoring examples. Citing examples provides evidence of a student's ability to instantiate abstract concepts. For example, it may be known that a five-year-old boy knows that a dog is an animal, but if he links dog to the instance *Doberman Pincher* with the linking phrase *is a type of*, it would also be known that he could identify an instance of the concept dog. When scoring these types of propositions, Novak & Gowin (1984) weighted each proposition with an example and other propositions equally. The limitation here is that since concept maps can showcase a students understanding of the essential relationships between key conceptual pairs in a given domain, it may be of less interest to depict an example of any one concept. Hence, examples of certain concepts may not evidence propositional or structural understanding but evidence more an understanding of an instance of a particular concept. If this is an outcome of interest to the assessor then students should be directed to add examples where applicable in their maps.

Comparing Students' Maps with a Master Map

Another scoring option that has gained wide acceptance is to compare a student map with an expert, criterion, or master map. The criterion map functions as a standard to evaluate (a) the acceptableness of concept selection, (b) proposition choice, (c) proposition accuracy, (d) map structure, etc. Criterion maps are difficult to construct because of challenges highlighted in the study by Acton, Johnson, and Goldsmith (1994). In their study criterion maps were constructed by field experts and a class instructor. They found that individual experts were highly variable in the specifics and in some instances the generalities of their maps. The course instructor, however, showed even greater map variability from the expert maps. To add to the intrigue, the student maps correlated much less with the instructor map than with the expert maps. This finding has serious implications for the viability of comparing students' maps with a mater map.

Combination of Strategies

The third strategy proposed by Ruiz-Primo and Shavelson (1996) is to score concept maps using both strategies – scoring the components of a map while using the criterion map as a guide. McClure et al. (1999) investigated six scoring methods that focused on different aspects of student maps including a holistic, structural, and relational evaluation. This study will be described in more detail in the section on the reliability ratings of concept-map scores. Suffice it to say, the relational scoring method (scoring each propositions separately) guided by a criterion map proved to demonstrate the highest reliability ratings of the other five methods. Hence, a combination of strategies or a triangulated method may provide greater reliability as well as build a stronger case for the validity of concept-map assessments.

Holistic Scoring Methods

While not as common, the holistic method has been studied in a few investigations. As mentioned previously, McClure et al. (1999) studied interrater reliability of raters rating concept maps with different scoring methods. One of those methods was the holistic scoring method where raters examined student concept maps and judged the mapper's overall connected understanding from the map on a scale of 1 to 10. This particular method was found to generate inconsistent ratings. The researchers reported that this might have in part been due to how cognitively taxing it is to account for map quality without a specific guide for scoring the detailed components of the map.

Concept-Map Assessment Component Summary

In conceptualizing the current study task, response format, and scoring method were each considered in the development and design of the two construct-a-map tasks to be investigated. As will be explained in greater detail later in this chapter, two variations of the construct-a-map task with a list of concepts provided (see Figure 11) were selected to be studied. The scoring methods were developed drawing from several recommendations made by those researchers who focus their research on the rating of the concept-map propositions.

Psychometric Properties

Assessment tools, if constructed properly, should provide accurate information regarding student knowledge, affect, and/or performance in a particular domain. In order for that to be the case, the student scores generated from an assessment must show evidence of being reliable and valid (Linn & Gronlund, 1995). The reliability and validity of ratings generated from an assessment constitute what is termed the psychometric properties of an assessment. These properties must be analyzed with concept-map assessments as well, or their use cannot be defended as a bona-fide evaluative tool.

Reliability

Nunnally (1967) defined reliability as “the extent to which measurements are repeatable.” He added, “any random influence which tends to make measurements different from occasion to occasion is a source of measurement error” (p. 206). In their review of concept-map assessment literature, Ruiz-Primo and Shavelson (1996) found that prior to 1995, few studies reported the reliability of concept-mapping scores. Instead of reporting reliability coefficients, most researchers provided percentages representing interrater agreement. Little has changed since their finding, with the exception of a few studies that have considered other sources of measurement error, such as the consistency of student rankings between raters (e.g., McClure et al., 1999), equivalence of test forms (Ruiz-Primo et al., 2001), score stability across test occasion, (Yin & Shavelson, 2004), internal consistency (Yin & Shavelson, 2004).

Estimates of the reliability of scores are affected by the nature of the task, the response format, and the scoring scheme that make up the concept-map assessment. For example, the more directed the task the easier the assessment is to grade and thus reliability and task directedness increase proportionately. Figure 15 depicts the relationship between levels of task directedness along with their associated reliability ratings.

Likewise, the simpler the scoring scheme the more reliable the student concept-mapping scores tend to be, because the cognitive load placed on raters is less taxing.

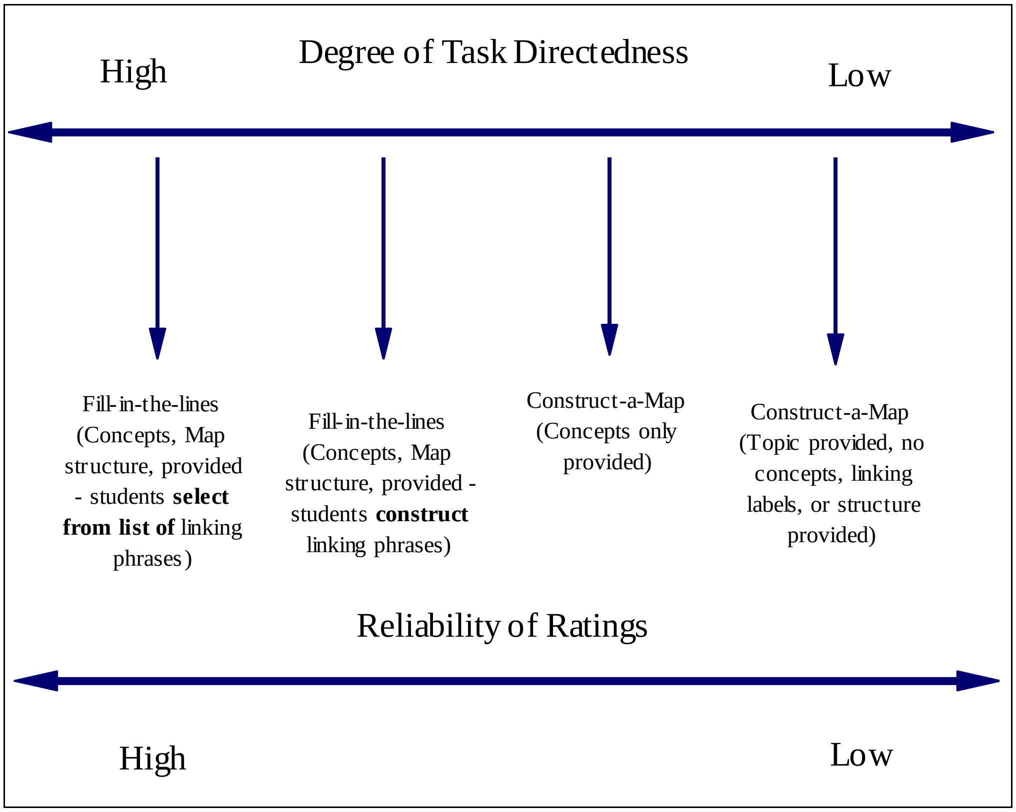


Figure 15. Degree of task directedness and the reliability of ratings.

Only a few researchers have compared the reliability estimates of different scoring schemes. Notably, McClure et al. (1999) used six pairs of independent raters to score 63 concept maps. In their study each pair of raters used one of six scoring methods: (a) holistic, (b) holistic with master map, (c) relational, (d) relational with master map, (e) structural, and (f) structural with master map. As mentioned previously, the holistic method consisted of raters examining each map and rating the mapper's overall understanding on a scale from 1 to 10. Raters using the relational method rated the correctness of each proposition on a three-point scale. The structural method was adapted from a method described by Novak and Gowin (1984). Each method was then used with a master map as a reference or guide for scoring the concept maps. The alpha reliability coefficients for the six methods used in their study ranged from .23 to .76. Ratings produced from raters employing the structural scoring method using a master map as a guide exhibited the lowest alpha coefficients and ratings produced from raters employing the relational scoring method using a master map as a guide exhibited the highest alpha coefficients.

According to McClure et al. (1999) other factors that may serve as sources of error in a concept-map assessment could include (a) variations in students' ability to follow concept-mapping conventions, (b) variations in the content knowledge (domain expertise) of those evaluating the concept maps, and (c) the consistency with which the concept maps are evaluated. This last factor is contingent in large part on the method by which concept maps are scored. The more taxing the cognitive load imposed by the different scoring methods on the raters the more likely the scores will be less reliable.

Classical Test Theory

Published concept-mapping assessment studies conducted prior to 2001 reported reliability coefficients generally based their analysis on classical test theory. Classical test theory is based on the decomposition of a student observed score into two component parts: the true score and an error score (Equation 1). The true score for an individual is defined as the expected mean of the distribution of the scores obtained by that person from an infinite number of repeated, independent administrations of the same test. The

$$X_{ij} = T_j + e_{ij} \tag{1}$$

notion of a true score is a statistical concept and is not directly observable. If an examinee were tested repeatedly on the same test, each obtained score would be either an over or under estimate of the person's true score.

Classical test theory assumes that (a) the true score for each examinee is a stable, fixed value that does not vary from one administration of the test to another administration of the test and (b) each examinee's error score and observed score will vary from one administration of the test to another. Certain types of measurement error can be measured using classical test theory including score consistency across testing occasions (stability), consistency across equivalent forms (alternate or parallel forms), consistency across items designed to measure the same trait (internal consistency), and consistency across rater-mediated tasks (interrater reliability).

Stability. Score stability represents the degree to which scores are consistent across testing occasions. Few studies have been conducted analyzing the stability of concept-mapping scores across testing occasions (see Ruiz-Primo et al., 2001). One of the reasons for this is that it is not feasible for students to take the same test on different testing occasions because the first occasion would have an influence on the second. If score stability is a scoring property of interest, then measures must be taken to diminish the influence of the first test administration on the second. Another form of score stability is the degree to which scores are consistent across rating occasions when each examinee's map is rated by the same raters on two or more occasions. In this case it is not the examinee test scores but the ratings given by raters that are examined for evidence of stability. This type of rater stability is called intrarrater reliability.

Parallel, alternate or equivalent forms. Two test forms designed to measure the same trait by sampling the same domain, are known as parallel or equivalent forms. A few studies have considered the reliability of equivalent or parallel concept-mapping forms. The few researchers who have considered it have focused their efforts on establishing if two forms that impose different constraints on students are parallel. For example, Ruiz-Primo et al. (2001) conducted a study that sought to determine the degree to which the construct-a-map and fill-in-the-map concept-mapping tasks were equivalent. While intuitively these two tasks would not be considered equivalent, the researchers sought to empirically confirm this assertion and identify and compare the divergent cognitive processes required to perform each task. This study had important implications for the potential use of concept-map assessments, for if the two tasks were appreciably equivalent this would have been taken as evidence that similar conclusions could be drawn from the ratings from both tasks. In addition, because the fill-in-the-map task is much easier to score, it could have defensibly been used in large-scale assessments. As expected, the evidence overwhelmingly demonstrated that the forms were not equivalent.

Internal consistency. As noted, internal consistency is a measure of the degree to which items in the same test measure the same trait or cognitive process. For example, if a math test consists mostly of items requiring simple computation plus one or two items that require mathematical reasoning plus computation, then student responses to these differing items would probably lack internal consistency. Items must belong to the same domain or subdomain and assess similar cognitive, affective, or performance outcomes to be internally consistent. Concept-map assessments are designed to measure some aspect of connected or organized understanding in a given content domain and must do so consistently to be considered internally consistent. Once again, in the study conducted by Ruiz-Primo et al. (2001) items on the fill-in-the-map task were randomly sampled in an effort to study the degree to which all potential propositions were interchangeable in evoking same cognitive process.

Interrater reliability. Any concept-map assessment that directs students to supply rather than select answers will require a rater to rate the map. Most mapping tasks involve rater-mediated scoring. Hence, another potential source of measurement error is the lack of interrater reliability. It differs from intrarrater reliability in that measurement error is a function of differences in rater to rater scoring rather than differences within individual raters across rating occasions. Interrater reliability has been reported in a several concept-mapping assessment studies (Barenholz & Tamir, 1992; Lomask et al., 1992; McClure et al, 1999; Lay-Dopyera & Beyerbach, 1983; Nakhleh & Krajcik, 1991; Ruiz-Primo et al., 2001; Yin & Shavelson, 2004).

As stated previously, in most instances interrater agreement has been reported in place of interrater reliability (Ruiz-Primo & Shavelson, 1996). Interrater agreement differs from interrater reliability in that it describes the degree to which raters assign identical ratings. In contrast interrater reliability describes the degree to which ratings assigned by the various raters correlate with each other. Ratings assigned by two different raters may be perfectly correlated even though none of them agree. If one rater is harsh and the other is lenient, their mean ratings will differ, but they could still have a high correlation.

Generalizability Theory

Generalizability theory is an extension of classical test theory that provides a way to partition the total variance in a set of ratings into separate, uncorrelated parts that are each associated with a different source of variability (Brennan, 1992, 2001; Cronbach, Gleser, Nanda, & Rajaratnam, 1972; Shavelson & Webb, 1991). G-theory is comprised of a generalizability study (G-study) and a decision study (D-study).

G-theory uses ANOVA to compute estimated variance components. Through the use of ANOVA both the main effects and interaction effects of more than one factor are computed. However, instead of computing *F*-ratios to test hypotheses, the ANOVA in a G-study produces an estimate of the variance component for each main effect and each interaction. G-theory thus goes beyond ANOVA in that it can be used to estimate the relative percentage of measurement error from each of these effects.

G-study. Instead of simply decomposing variance attributed to a person's ability and variance contributed by unexplained error variance, G-theory permits the researcher to decompose the error variance into explainable and unexplainable error components as depicted in Equation 2. This is calculated by conducting a G-study.

Equation 1

$$\sigma^2_{\text{total score}} = \sigma^2_{\text{object of measurement}} + \sigma^2_{\text{raters}} + \sigma^2_{\text{p x r interation}} + \sigma^2_{\text{residual}} \qquad (2)$$

If the study were designed to have each student's map rated by two or more raters on two or more occasions, then G-theory could be used to partition the total variability in the ratings into variance components due to each of the following sources of variation:

(a) systematic variability between the individual students *(p)*, (b) variability between raters *(r)*, and (c) variability across rating occasions *(o)*. In addition to the variance components for each of these main effects, G-theory permits the researcher to obtain estimates of variance components for the interactions among these effects, including (a) inconsistencies of raters' rating of particular persons' concept map *(p x r)*, (b) inconsistencies from one occasion to another in particular persons' concept-map ratings *(p x o)*, (c) constant effect for all persons due to differences in raters' stringency from one occasion to another *(r x o)*, and unexplained error *(p x r x o, e)*. By comparing the relative size of these estimated variance components, a researcher can determine which sources of variation are most troublesome and which, if any, need to be addressed in an attempt to reduce unwanted inconsistencies in the ratings.

D-study. The estimated variance components obtained from a G-study can be used as a basis for the D-study in making decisions and applications for a particular purpose. The G-study establishes the general characteristics of the measuring procedure, and then the D-study assesses those characteristics in a particular decision-making context or frame of reference. The purpose of the D-study is to make the best use of the information provided by the G study in applying it to social science measurement decisions (Shavelson & Webb, 1991). In a D-study, the researcher must do the following:

1. Define a *universe of generalization* (the number and breadth of facets to be generalized across such facets as raters, occasions, tasks, scoring schemes, etc.).
2. Specify the proposed interpretation of the measurement: *relative decisions*—rank order of individuals standing relative to one another concept-mapping scores, or

absolute decisions—an individual's absolute score without regard to other student scores.

3. Use the G-study estimates of measurement error and magnitude to evaluate and maximize the effectiveness of each facet to minimize the error and maximize reliability; in other words, a D-study would be conducted to project what the reliability coefficients would be if the levels of raters or occasions were increased or decreased. Such decisions are made to project the most cost-effective rating design that could be used in subsequent studies.
4. Use the G-study estimates of measurement error and magnitude to evaluate alternative D-study designs with crossed or nested, random or fixed, facets (Shavelson & Webb, 1991).

Concept Map Research Using G-Theory

Very few researchers have utilized G-theory to analyze measurement error associated with the use of concept maps. The sources of error that could be considered include concept sampling, proposition sampling, task sampling, response format sampling, occasion sampling, scoring system sampling, rater sampling, etc. (McClure et al., 1999; Ruiz-Primo et al., 2004; Yin & Shavelson, 2004). Sources of variation could also be calculated from the interactions between any of the preceding sources of measurement error.

McClure et al. (1999) analyzed the error contributed to the overall variation scores by the person-by-rater interaction. Yin & Shavelson (2004), following the research design used by Ruiz-Primo et al. (2001) considered the interactions between student and mapping task, student and sampled items (blank nodes and blank linking phrases), and sampled items and mapping task. Outside of these researchers almost no others have used G-theory as an analytical method in studying the reliability of concept-mapping scores.

A fertile ground of research is available for educational researchers to use this robust analytical method in pinpointing the sources of measurement error that are present due to the nature of any given concept-mapping task, response format, or scoring method.

Validity

According to Messick, (1988) validity is “an overall evaluative judgment, founded on empirical evidence and theoretical rationales, of the adequacy and appropriateness of inferences and actions based on test scores” (p. 33). The theoretical rationale governing the use of concept-map scores has been outlined in the first part of this chapter. However, empirical evidence collected from concept-mapping assessments as a demonstration of the degree to which the theoretical rationale can be substantiated, is relatively scarce. Included in concept-mapping validity study are questions regarding the degree to which inferences (interpretations) and actions (decisions) based on the test scores are appropriate (Ebel & Frisbie, 1991).

Concerning concept-map assessments, Ruiz-Primo et al. (2004) asked two questions regarding the validity of student concept maps and their scores: “(1) Does the assessment evoke the intended behaviors? and (2) Is there a correspondence between the intended behaviors and the performance scores?” (p. 9). The intended behaviors in this context would consist of a student constructing a map that receives a score that to some measurable degree reflects their organized understanding of a particular domain or sub-domain.

Hence, the validity of concept-mapping assessments can be studied in an effort to ascertain the degree to which those scores measure the attribute, trait, or ability they purport to measure. McClure et al. (1999) explained, “for optimal validity, the concept-mapping task must result in an artifact (a concept map) that accurately reflects the content and organization of students’ knowledge” (p. 478). In the case of this study, the focus was on the degree to which the student concept-map scores (generated from two construct-a-map tasks) measured student understanding of conceptual interrelationships. The scores become less valid when they reflect something other than this trait. Several aspects of concept map validity have been studied by concept-mapping researchers, including content, criterion, and construct validity.

Evidence of Content-Related Validity

Evidence of content-related validity is collected in an attempt to determine to what extent the items of an assessment task constitute a representative sample drawn from the domain being measured. Most tests consist of a sample rather than a census of all of the possible test items in a content domain. This is because the majority of content domains contain more items than can feasibly be tested all at once or over time. Well-designed concept-map assessments are developed after having identified all of the concepts and propositions within the boundaries of a given domain. According to Ruiz-Primo and Shavelson (1996),one important criterion for evaluating content validity is whether domain experts were used at the outset to judge the representativeness of concepts and linking phrases of expert maps drawn from the target domain. This step is evident in a study conducted by Rice et al. (1998). In their effort to link concept-map items with instructional objectives, they created a table of specifications from which all test items including concept-map assessment items were sampled. As noted by their study along with recommendations made by Ruiz-Primo and Shavelson (1996), ensuring that test scores evidence a high degree of content validity should occur in the early stages of test development.

Once the boundaries of the domain are established, key concepts and/or propositions are randomly selected for use on a test. What is tested (concepts, linking phrases, or both) is contingent on the learning outcomes to be assessed along with the corresponding mapping-task that is to be used. For example, Ruiz-Primo et al. (2001) created an expert map of the key concepts and linking phrases representing the structural interrelationships of concepts from a unit entitled “Chemical Names and Formulas" in a high school chemistry course. The researchers then created an expert map that contained all of the key concepts from this unit. Three concept-map assessments were then created, two of which were developed using concept sampling.

In the case of the first assessment, the fill-in-the-node task (see Figure 6), a certain number of concepts or nodes were randomly blanked out. With the second assessment, the fill-in-the-link task (see Figure 5), the linking phrases were likewise randomly blanked out. These blanked out components of the map represented a sample of the domain that students were required to account for on the test. However with the third assessment, the construct-a-map task, they did not sample the concepts in this manner.

The construct-a-map task (see Figure 9), which is the task under investigation in this study, by its very nature does not permit the type of concept or linking-phrase sampling just described. That said, other methods could be used for sampling concepts with this assessment. First, a list of key concepts from a strongly interrelated domain could be randomly generated. The strength of the inter-associations between the concepts is crucial here; otherwise, if a series of concepts with weak associations are randomly selected the propositions will either be too general, not important, and/or forced. Second, if the domain possesses a series of strongly associated clusters of concepts, then the clusters rather than the concepts could be sampled. The unique nature of the content structure and conceptual interrelationships in a given domain must be taken into account before a random sample of concepts or clusters is drawn with this task. Most researchers create a convenient sample of concepts for this type of task. While practically more feasible, it is more challenging to ensure content validity when the concepts and/or the propositions are not randomly sampled.

Evidence of Criterion-Related Validity

To establish criterion validity, scores from a new measure are correlated with the scores from a criterion measure known to be valid. When the criterion measure is collected at the same time as the measure being validated the goal is to establish concurrent validity; when the criterion measure is collected later, the goal is to establish predictive validity. The challenge associated with attempts to establish criterion validity is to find another measure that has been shown to generate scores that validly measure the same construct or trait the target measure under investigation is also designed to assess. If the scores of the criterion measure have been shown to be valid then this begs the question, why not use the criterion measure instead of the measure it is being tested against (e.g., concept-map assessments)? In the case of concept-map assessment scores, the criterion measures used to establish their validity are either too time-consuming to score (i.e., interviews), are clouded by other constructs (i.e., writing ability with essays), or do not manifest evidence of students' conceptual frameworks (i.e., multiple-choice questions). In other words, while sharing some of the facilitative properties of other measures to assess organized understanding, it is postulated that concept maps provide uniquely viable evidence beyond what other criterion measures may contribute. It is for these and other reasons that concept-map assessments are viewed as an important alternative source of information regarding students' conceptual frameworks.

Researchers have hypothesized that concept-map assessment scores will never correlate perfectly with scores on other traditional assessments, because they measure more directly student-organized, structural, or connected understanding (Novak & Gowin, 1984). Novak and Gowin argued that the low correlations between scores on concept-map and multiple-choice items in their studies provided evidence that concept maps measure something traditional items cannot or do not. However, more recent studies have shown concept maps to have much higher correlations with traditional test items (Rice et al., 1998) and standardized tests (Anderson & Huang, 1989) then was previously reported by Novak and Gowin. It is important to note that the scoring method in both of these studies did not include scoring map hierarchy as was the case with Novak and Gowin's scoring scheme but focused exclusively on scoring the propositions. Rice et al. observed the following with regards to this point: "the method of scoring maps, particularly the criteria for allotting points, is a critical determinant of the strength of the relationship between map scores and scores on other assessments" (p. 1107). As established earlier, accounting for map hierarchy is a challenging venture. By removing this scoring feature, score correlations between concept maps and traditional test items have been reported to increase dramatically.

While it is possible that concept-map scores reflect more of a student's connected understanding than other measures, it is also possible that other measures that take into account proposition accuracy may also measure something of student organized understanding as well (Rice et al., 1998). If this is the case, then studying the criterion validity of concept mapping and another valid measure test scores would have merit.

Evidence of Construct-Related Validity

A construct is a theoretical conceptualization posited to drive some facet of human behavior. Constructs, such as self-efficacy, extraversion, or knowledge structures are posited by social scientists to be driving observed variables (e.g., charitable acts, effective problem solving). Building a case for the construct validity of a measure is the ultimate objective of all test developers. The process of providing evidence of construct-related validity is called construct validation. Ebel and Frisbie (1991) describe construct validation as "the process of gathering evidence to support the contention that a given test indeed measures the psychological construct the maker's intend for it to measure" (p. 108). It is important to note that efforts to build a case for construct-related validity almost always include evidence of content and criterion-related validity (Messick, 1995).

Construct validation begins with a working definition of the construct. The construct definition requires careful consideration, which includes theoretical and empirical testing in an effort to represent conceptually the construct of interest. As described in an earlier section of this chapter, concept-map assessments are designed to tap into the construct of a person's conceptual framework. Ruiz-Primo and Shavelson

(1996) provide a conceptual link between concept maps and the notion of a conceptual framework, explaining that, “how we assess a knowledge structure should be consistent with how we assume knowledge is organized” (p. 573). The way many educational psychologists have assumed knowledge to be organized has drawn upon many theories including semantic network theory (Collins & Quillian, 1966), propositional network theory (Pylyshyn, 1984), schema theory (Bartlet, 1932), hierarchical memory theory (Ausubel, 1968), associationist theory (Deese, 1965), etc. These theories essentially highlight the need for knowledge to be organized and structured in a way that facilitates understanding and retention.

With the construct definition delineated (i.e., students’ conceptual framework), an effort can proceed to analyze a link between the mapping task and the cognitive activities it evokes. A few studies have investigated the degree to which concept-map scores indirectly measure the construct of a conceptual framework (Acton et al., 1994; Ruiz-Primo et al., 2001). Some research purports that students do not have a vast store of knowledge (Nicoll et al., 2001). Leonard and Penick (2000) suggest that what knowledge they do have is typically disjointed and not well-connected. Acton et al. found that the concept maps of successful learners contrasted with novices provided evidence that successful learners or experts possess more elaborate, interconnected knowledge structures than do novices. The question to be considered is, to what degree do the cognitive activities evoked by a concept-mapping assessment task draw upon the theorized construct of interest, and hence distinguish between well-connected, well-organized and poorly-connected, poorly-organized understanding?

Messick (1989) describes two major threats to construct validity: construct underrepresentation and construct-irrelevant variance. Some of the variability in students' scores may be more an artifact of the task demand, task constraint, response mode, or scoring system than a reflection of their organized understanding of the subject being tested. For example, in the case of a study conducted by Ruiz-Primo et al. (2001) comparing the validity of two-mapping tasks, the more highly directed task was scored in such a way that it did not represent varying degrees of accuracy or completeness in student linking phrases. It was scored as either correct with a point value of one or incorrect with a point value of zero. This scoring method does not take into account the varying degrees of accuracy and hence constitutes construct underrepresentation. Yin et al. (2005) found that their *S mapping* task, which asked students to construct a map selecting from predetermined linking phrases (see Figure 10), caused students to engage in a process of elimination to select correct answers. This strategy does not constitute the construct of interest and would be an example of construct-irrelevant variance.

As is the case with content validity, construct validity must be built into the test development process at the outset. A case for construct validity is made by drawing evidence from various sources including content and criterion validity. In summary, efforts to establish content and criterion validity provide evidence that builds a case for making valid construct-related inferences about the meaning of student concept-map ratings.

Rationale for the Current Study

The current study was conceived by considering recommendations in the concept-map assessment literature. These recommendations suggest that studies be conducted to aid in the collective effort to provide empirical evidence that sheds light on the viability of using concept-map assessments as a defensible measure of students' structural knowledge (Francisco et al., 2002; Liu & Hinchey, 1996; McClure et al., 1999; Rice et al., 1998; Ruiz-Primo et al., 2004; Ruiz-Primo et al., 2001; Yin et al., 2005, etc.).

C-Mapping Task

From this review it became apparent that the construct-a-map with a list of concepts provided (see Figure 11) was the most promising assessment task for use in most educational settings except in the case of large-scale assessments. Ruiz-Primo et al. (2001) labeled this task the *C-mapping task*, to which it will be referred to hereafter in this and the chapters that follow. The C-mapping task has the potential to provide the strongest evidence of rating reliability and construct-related validity than any other concept-map assessment task (Yin et al., 2005). It is restrictive enough so as to provide acceptable reliability, yet not so restrictive to suffer from construct under-representation or construct irrelevant variance.

Challenges with Scoring C-Mapping Task

As promising of a measure as it is, several challenges associated with this task must be overcome before it can be deemed a defensible tool for measuring student-connected understanding. Yin et al. (2005) commented on this point, explaining that the open format "leads to great uncertainty in its structure, the number of propositions and the proposition choices" (p. 182).

Let us consider why this is the case by looking at the challenge of scoring proposition choice. The number of propositions a student constructs is a function of the propositions he/she decides are important enough to merit constructing. Making an appropriate proposition choice is determined by a student's ability to differentiate between those propositions that are important to an understanding of the map topic and those propositions that are not important to such an understanding. Students that are more knowledgeable may choose to construct important propositions, while less knowledgeable students may choose to construct less important propositions as they relate to the overall topic of the map. This can present a challenge; if the scoring rubric is not carefully constructed and adhered to, students that are less knowledgeable conceivably could obtain the same or even higher scores than their more knowledgeable counterparts (Kinchin, 2000).

As an illustration, with a list of four concepts it would be possible to construct a total of six linking phrases. Let us say that each linking phrase was scored on an accuracy scale of 0 to 2. If all four concepts have strong associations with one another, then knowledgeable students would be expected to construct six propositions (concepts and linking phrases) on their map scoring a total of twelve points possible. However, what if only three pairs of concepts possessed strong interrelationships with each other from the list of six concepts? How should less-important propositions be scored? If they were scored at all, then a student who receives full credit for accurately and completely linking more-important propositions but decides to not to connect the less-important ones would get a score of 6 (see Figure 16). If a less knowledgeable student accurately but not completely connects the three important propositions as well as accurately connecting less-important propositions, this student could also receive a score of 6 (see Figure 17).

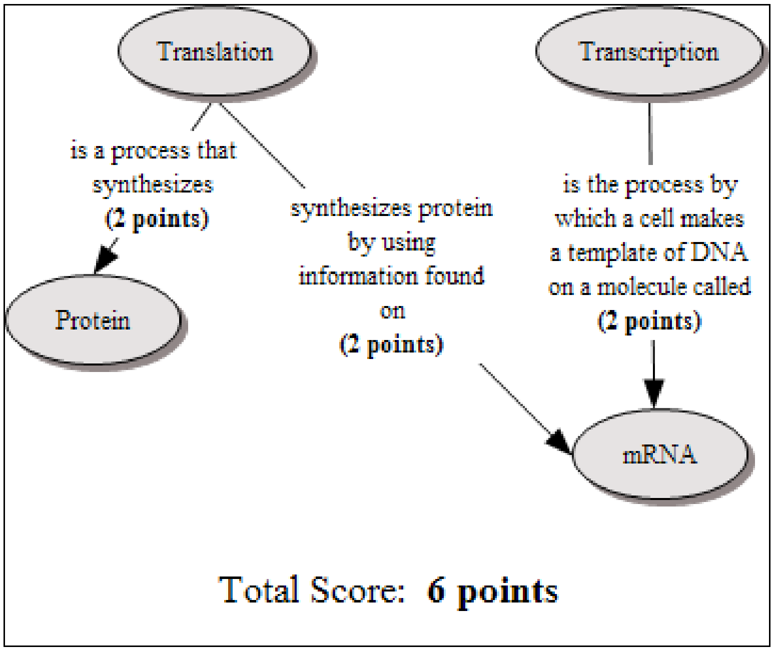


Figure 16. More-knowledgeable student's map.

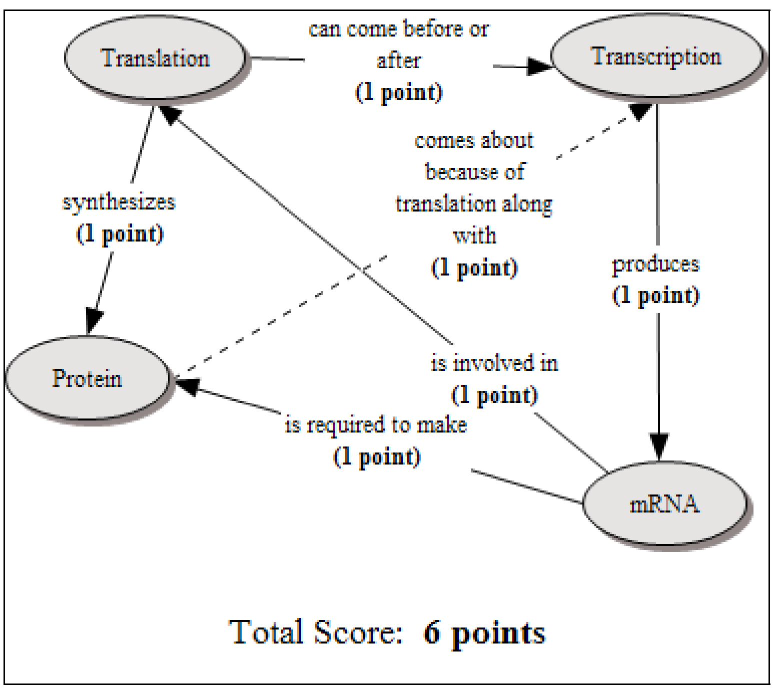


Figure 17. Less-knowledgeable student's map.

What could an assessor conclude from a score of 6? Unless they examined the map directly, they would not be able to ascertain with any degree of certainty if the score of 6 represents the effort of a less or more knowledgeable student.

Solutions Under Investigation

This study represents an attempt to analyze empirically the psychometric properties of two C-mapping tasks designed to account for proposition choice as well as accuracy, completeness, and relevance. Proposition relevance differed from proposition choice. Proposition relevance referred to the relevance of the information in the linking phrase to the overall topic of the map and not to the decision to link the two concepts in the first place. Proposition choice, however, was a rating element that directed the attention of the raters to consider the degree to which the concepts students chose to be linked were actually important or relevant to the overall topic of the map regardless of what was contained in the linking phrase.

Along with accounting for proposition choice, two slightly different C-mapping tasks were investigated that varied according to task constraint. The first task drew upon an approach used by Rice et al. (1998) where students were assigned negative points for inaccurate links and directed not to add other relevant concepts. The hypothesis was that if students were aware that they would be penalized in this manner, then they would take greater care to construct more well thought out propositions within their maps. The second task was designed based on a recommendation made by Yin et al. (2005) where students were encouraged to construct as many links as they like as well as to add other relevant concepts to their maps. In summary, both tasks directed raters to weight propositions based on their level of importance and account for other key rating elements under different mapping constraints.

CHAPTER 3: METHOD

Study Context

In the summer of 2006, Dr. Gary Booth, professor of Biology at Brigham Young University, expressed interest in pursuing ongoing research designed to provide information regarding the use of concept maps as an instructional and evaluative tool in his integrative biology course. He had used concept maps for both instructional and assessment purposes in his classes during the previous two years. Hence, it was not a new intervention introduced for the purposes of this study. During the Fall 2005 semester, the author conducted a pilot study in the same course taught by Dr. Booth. The study was conducted with the purpose of better understanding the variables that would likely impact the success of the current study.

Participants

The participants were selected from 120 freshman academy students enrolled in Dr. Booth's introductory biology course at Brigham Young University. Freshman academy is a learning community consisting of a group of first-year students who share three or more linked classes and participate in activities that are designed to promote unity and enhance the academic experience. The demographic composition of freshman academy students usually reflects that of the incoming freshman class in gender, major preference, and academic preparation. All incoming freshmen were eligible to participate in the program on a first-come, first-served basis. The majority of the students came from the western United States, with large minority from other parts of the country and a small number of international students. International students were required to attain a high level of English proficiency in order to be enrolled at the university.

All 120 students were invited to sign a document of informed consent (Appendix A) expressing their willingness to participate in the study. Student participation was classified into two categories: (a) instructional activities and exercises designed to assist students in organizing the concepts they learn through the use of concept maps and (b) evaluative activities designed to assess their organized understanding of the course concepts. The instructional and evaluative activities were refined based on the recommendations that came from the pilot study. While the instructional activities were not the focus of the study, they were deemed critical in helping the students become familiar with concept-mapping conventions so that ratings generated from the concept-map assessments would have the best chance possible of reflecting their organized understanding. Since the instructional portion of the course was not under the purview of the author, student participation in using concept maps as an instructional tool was not made part of the informed consent document. The only activities introduced by the study were student interviews conducted after both midterm exams and the rescoring of concept-mapping and essay test items on those same exams. Student grades were not affected by the outcome of the rescoring.

Instrumentation

On both midterm exams three tasks were used as part of the implementation of the study: Two C-mapping, two essay tasks, and a set of interview questions. Hence, a total of ten assessment tasks were designed and developed for the purposes of this study. Under Dr. Booth's direction the teaching assistants selected key concepts from each unit. The learning of these concepts and their interrelationship with other key concepts were deemed critical by the teaching assistants in gaining a meaningful understanding of each unit. Before each exam a list of 13 to 16 concepts were selected from one unit to comprise the list of concepts to be used in one C-mapping and its corresponding essay and structured interview tasks.

Concept-Map Measures

The task and rubric for both C-mapping tasks will be described in this section. These elements were developed iteratively during the pilot study. The rubrics for both tasks accounted for proposition importance by directing the rater to consider the degree to which two concepts were closely related within the context of the topic of the map. As noted these rubrics also accounted for proposition accuracy, completeness, and relevance.

C-mapping Task 1

The first C-mapping task on the first and second midterm exams directed students to make as many connections as they desired from a list of concepts (Appendix B & C). However, they were instructed that incorrect propositions would be penalized by deducting one-half point from their score. Students were directed not to add other relevant concepts to their map and were provided a copy of the rating rubric as a guide as they constructed each proposition.

The rubric used for C-mapping task 1 was essentially the same for both exams with slight modifications made to the rubric on the second exam. These changes were made in an attempt to overcome rating challenges discovered after conducting a *generalizability study* after the first midterm exam. For example C-mapping task 1 on the first exam directed raters to consider whether students communicated accurate and essential relationships between two closely related concepts. Several of the raters suggested to the author that students be reminded on the second midterm concept-mapping task that their linking phrases would be compared to the information set forth in the course text (syllabus), lecture or lab sessions. Therefore, the new description for one of the levels of the rubric on the second-exam stated, "Communicates accurately the essential relationship between two concepts as described in the syllabus, class lecture, or lab" (Appendix C).

C-mapping Task 2

The second task directed students to make as many connections as they desired; however, in the case of this task no negative points were assigned for inaccurate propositions (Appendix D & E). Unlike the previous task students were encouraged to add other relevant concepts if they so desired. Raters were then on the look out for two relevant concepts in particular that when connected to one of the concepts from the list would constitute an important proposition. As was the case with the first C-mapping task rubric, similar adjustments were made to the second C-mapping task rubric on the second midterm exam.

Criterion Measures

Essays

Task 1. The first essay item directed students to explain the interrelationships between the following concepts: *activation energy*, *enzymes*, *competitive inhibition*, and *non-competitive inhibition* (Appendix F). Note that these four concepts were also among those concepts listed on the first C-mapping task.

A slight modification was made to the first essay task on the second midterm exam. Students were directed to write an essay connecting three concepts that were not closely related but represented key concepts in one of the units of the course. They were then encouraged to connect the unrelated concepts to one another using additional relevant concepts. The first essay task on the second exam directed students to explain the interrelationships between the concepts *anti-codons, protein,* and *transcription* (Appendix G). After several trials this approach was considered to be an effective way to distinguish between knowledgeable and less knowledgeable students. However, during the course of the study there were a few instances where students made connections that the teaching assistants had not anticipated, and hence slightly confounded one of the analyses. The specifics of these confounds will be reported in chapter 5.

Task 2. The second essay task on the first midterm exam directed students to express the interrelationships between the concepts: *ATP*, *ADP*, *Energy*, and *Terminal Phosphate* (Appendix H). These four concepts were a part of the list from the second construct-a-map task. The second essay task on the second midterm exam directed students to express the interrelationships between the concepts: *Anti-bodies, exotoxins*, and *microphages* (Appendix I). These three concepts were among those concepts form the list of concepts on the corresponding C-mapping task. The second essay task on the second exam followed the same structure as the first essay task on the same exam.

Interviews

It was determined at the outset of the study that structured interviews would be the most appropriate type of interviewing method. This decision was based on the need to provide specific prompts that would evoke specific expressions regarding conceptual interrelationships. Within a week after both midterm exams, a sample of students was invited to respond to 14 and 10 interview questions respectively (Appendix J & K). Each of the twelve interview questions directed students to verbally make meaningful connections between two to four concepts.

The last two interview questions invited the students to share their impressions of concept mapping as an instructional and evaluative tool in the course. The first set of interview questions dealt with interrelationships between concepts found on the first C-mapping task and the second set of interview questions dealt with interrelationships between concepts found on the second C-mapping task.

Rater Training

Raters made up a key component of what constitutes the instruments of this study. The raters and rubrics taken together constituted the ten rating instruments. Along with their teaching assistant responsibilities, four of Dr. Booth's teaching assistants were hired as concept-mapping raters. Three of the four raters had rated concept maps the previous year during the pilot study along with essays and interview transcripts.

The teaching assistants were retrained on how to construct concept maps during the first week of the semester. An instructional packet (Appendix L) was used to guide them through the process of map construction. During the training session the author rated several propositions using the rubric from the first C-mapping task. Raters were invited to then rate five other propositions independently of each other. Afterwards each rater reported their ratings. Discrepant ratings were analyzed with each rater explaining their rating rationale. This process continued until a consensus was achieved. The same rater training was implemented for both essays and interview-generated data. Hence, a person-by-rater-by-occasion fully-crossed design was conducted so as to run G and D-studies on the essay and interview transcript ratings.

Research Design

Student Generated Data

The plan for collecting data from the students is depicted in Table 2. In late September, students took the first midterm exam. They responded to two concept-mapping tasks and two essay tasks. The exam was divided into two sections. The first section directed students to respond to two essay questions (Appendix F & H). The essays were followed by approximately 100 mostly multiple-choice and some short-answer questions. Students were then directed to submit their completed exams and pick up the second section of the exam comprising of the two C-mapping tasks (Appendix B & D). The test administration was divided in this way to prevent the students from referring to their essay when constructing their concept maps.

Within a few days after the exam closed, 24 concept maps were selected and their authors chosen to be interviewed using a qualitative sorting stratified sample method. A stratified random sample of 24 students on the first exam and another stratified sample of

Table 2

Plan for Collecting Data from Students

Assessment Set	Essays	C-mapping tasks	Structured Interviews
1st Midterm	2	2	1
2nd Midterm	2	2	1

24 student concept maps on the second exam were selected to be rated. In order to obtain a sample of students with varying mapping abilities, students maps were sorted into three strata of mapping quality: (a) high, (b) medium, and (c) low. In conducting the qualitative sorting method, two biology teaching assistants categorized the maps based on the accuracy of student linking phrases on three to four key concept-map propositions. The two research assistants then compared their three stratified groupings and came to a consensus where there was disagreement in map classification. Eight maps were selected randomly from each of these three ability groups constituting a stratified randomly selected sample of 24 students. The same 24 student concept maps, essays, and interview transcripts were analyzed as part of the study.

Students took the second midterm exam by late October and as with the first midterm exam responded to two essay and two C-mapping tasks. Likewise, within a few days of the exam closing a randomly stratified sample of 24 students were selected to be interviewed.

Rater Generated Data

After each of the two midterm exams closed, the four raters rated 24 task 1 concept map-assessments and 24 task 2 concept-map assessments on two separate rating occasions for a total of 48 concept maps per occasions (Table 3). Over a two-week period of time the raters followed the same rating schedule with the essays (Table 4) as well with the interview transcripts (Table 5). Three to four days separated each rating occasion.

Table 3

Concept Map Rating Schedule First Week after Exam

	Occasion 1				Occasion 2			
Exam 1 & 2	Rater1	Rater2	Rater3	Rater4	Rater1	Rater2	Rater3	Rater4
Task 1	24	24	24	24	24	24	24	24
Task 2	24	24	24	24	24	24	24	24

Table 4

Essay Rating Schedule Second Week after Exam

	Occasion 1				Occasion 2			
Exam 1 & 2	Rater1	Rater2	Rater3	Rater4	Rater1	Rater2	Rater3	Rater4
Task 1	24	24	24	24	24	24	24	24
Task 2	24	24	24	24	24	24	24	24

Table 5

Interview Rating Schedule Third Week after Exam

	Occasion 1				Occasion 2			
Exam 1 & 2	Rater1	Rater2	Rater3	Rater4	Rater1	Rater2	Rater3	Rater4
Task 1	24	24	24	24	24	24	24	24
Task 2	24	24	24	24	24	24	24	24

Analysis

Two separate analytical methods were employed to answer the reliability- and second validity-related research questions.

Research Question 1: Generalizability Study

The reliability-related questions were answered using generalizability theory (G-theory). As noted in chapter 2, G-theory permits researchers to compute reliability-related information through the conducting of two separate studies: a generalizability study (G-study) and a decision study (D-study).

The G-study was conducted using GENOVA software (Crick & Brennan, 1983) to analyze the variability between main and interaction effects found in the two-facet, fully crossed design with four raters rating 24 concept maps on two separate rating occasions. The variance components were computed and then used to calculate the percentage of variance due to the following sources of variability in the ratings: (a) dependable differences in the student's conceptual understanding (desirable variance), (b) inconsistencies between raters, (c) inconsistencies within raters from one rating occasion to another, (d) the various two-way interactions among the variables named above, and (e) unexplained variability.

The author made the decision to make task a fixed facet rather than a random facet. This was done because the two tasks in the study were similar enough that they did not represent a generalizable or interchangeable sample of the universe of admissible concept-mapping tasks. An analysis implication of this decision was that separate G-studies were performed on each C-mapping, essay, and interview task.

Research Question 2: Generalizability Coefficient

Implementing a fully-crossed design permits the estimation of a reliability coefficient to be computed for one rater rating on one rating occasion. This estimate may be of interest to educational practitioners who generally have limited resources and are unable to rate their student concept maps on more than one occasion. It was also determined early on that for purposes of this study the reliability coefficients would be used for making relative decisions. Since concept-map assessments are still in the experimental stages of their development, it was deemed inappropriate to compute a reliability coefficient for the purposes of comparing student performance to a standard. Hence the generalizability coefficient (for making relative decisions) not the phi-coefficient (for making absolute decisions) was computed.

Research Question 3: D- Study with the Same Design

Instead of making inferences about a student's ability from a single rating, we can obtain a more reliable rating of a student's ability to conceptually map a number of related concepts by increasing the number of occasions and raters. The data computed in the G-studies was used to project how the reliability of the mean rating for each student varied as a function of increasing or decreasing different levels of each facet in the study design. In this way an optimal increase in the number of facets was considered that would provide the greatest increase in the generalizability coefficient within the constraints of given resources.

Research Question 4: D-Study with Different Designs

As explained in chapter 2, G-theory also permits researchers to consider other more feasible designs than the fully crossed design. The following alternative designs were considered in this study:

1. Raters nested within occasion crossed with persons design (see Figure 18). In this design a set of two raters rate all concept maps on one occasion and then another set of two raters rate all concept maps on another occasion.
2. Raters nested within persons by occasion design. In this design one set of two raters rates half of the concept maps on the first occasion and another set of two raters rates the other half of concept maps on another occasion (see Figure 19).
3. Raters nested within persons by occasion design (see Figure 20). This design is identical to the first nested design but in this case one set of four raters rates half of the concept maps on the first occasion and then another set of four raters rates the other half of the concept maps on the second occasion.

	Occ 1				Occ 2			
	R1	R2	R3	R4	R1	R2	R3	R4
1	X	X					X	X
↓	X	X					X	X
12	X	X					X	X
13	X	X					X	X
↓	X	X					X	X
24	X	X					X	X

Figure 18. Raters nested within occasion crossed with person.

Note. X indicates rating and □ indicates no rating.

	Occ 1				Occ 2			
	R1	R2	R3	R4	R1	R2	R3	R4
1	X	X						
↓	X	X						
12	X	X						
13							X	X
↓							X	X
24							X	X

Figure 19. Two raters nested within person crossed with occasion.

	Occ 1				Occ 2			
	R1	R2	R3	R4	R1	R2	R3	R4
1	X	X	X	X				
↓	X	X	X	X				
12	X	X	X	X				
13					X	X	X	X
↓					X	X	X	X
24					X	X	X	X

Figure 20. Four raters nested within person crossed with occasion.

Research Question 5: Criterion Validity Study

Analysis of Content-Related Validity

Content validity was built in to the development of each concept-mapping assessment. Six teaching assistants under the direction of Dr. Booth came to a consensus on the fundamental concepts to be selected from each chapter of Dr. Booth's syllabus and created corresponding criterion maps. Selected concepts were used for each concept-map homework assignment along with exam concept-map, essay, and interview tasks. These criterion maps were used as a guide for rating the concept maps after each midterm exam. As noted earlier, expert maps are challenging to develop because experts themselves vary in the way in which they represent their knowledge structurally via concept maps (Acton et al., 1994). By coming to a consensus among the course content experts on the list of key concepts to be selected from each unit for the criterion map, expert variability was held constant.

Analysis of Criterion-Related Validity

Pearson correlations were calculated between C-mapping task scores and their corresponding essay scores as a measure of concurrent validity and their corresponding interview scores as a measure of predictive validity. The Pearson correlations along with their associated *p-values* were calculated using SPSS statistical software. A two-facet fully crossed design (four raters rating on two occasions) was likewise conducted with the essay and interview tasks to assess the degree to which these criterion measures were rated reliably.

An average rating for each student across four raters and two rating occasions was calculated for concept-map, essay, and interview tasks. A Pearson correlation was then computed between these averaged person ratings. It should be noted the Pearson correlations were computed only between those propositions that could be made on both the concept map and the corresponding criterion measures. For example, across the four essay tasks students were directed to interrelate from three up to seven or more concepts. The concept maps directed students to construct propositions between ten to sixteen concepts. The correlations were computed only between propositions that could be constructed on both the concept map and the essay tasks rather than between those propositions not shared by both tasks. This was also the case when correlating ratings between concept-map and interview tasks.

Procedures

Modifications were made to the main study based on the author's experiences with the pilot study the prior year. These modifications were made in order to enhance the student learning experience with concept maps and make it more likely that the assessments would generate ratings evidencing student connected understanding rather than construct irrelevance. The following changes were made:

1. Putting a greater emphasis on the ends not the means; in other words,, placing emphasis on student-organized understanding rather than using concept maps as an end in and of themselves.
2. Providing concept-map training along with meaningful opportunties for feedback to ensure that student concept maps had the greatest possibility of measuring student ability to construct important, accurate, complete, and relevant propositions.

Focus on Ends

During the pilot study, many students concluded that concept mapping was an incidental but not integral part of the course. Several students explained in their post-midterm exam interviews that the concept-mapping exercises felt more like busywork than a meaningful learning activity. Concept maps were marginalized because not only were students learning new content, but simultaneously they were learning a new system for structuring that content. Along with this factor, during the pilot study training and group feedback focused mainly on developing student skill with concept-mapping conventions and not on the end goal of constructing a meaningful organized conceptual understanding of the material. Kinchin (2000) explains that concept mapping cannot be simply a “tack on” (p. 67) to other class methods but must be integrated with those methods in achieving the end goal of student content mastery.

Before the Fall 2006 study commenced, Dr. Booth, the author, and several teaching assistants decided that one of the course objectives would be for students to come away with a meaningfully organized understanding of biology concepts taught in the course. It was further decided that this point would be emphasized repeatedly as students constructed their maps and received feedback. Dr. Booth’s teaching assistants reinforced this point through feedback given after weekly homework assignments.

During the first recitation session of the semester it was explained to students that the objectives of the course included the goal that each student learn and understand biological facts, biological concepts, and how those concepts interrelate with one another. It was further explained that several methods could be employed to assist them in developing a useful organized understanding of the content. They were told that concept mapping was the tool of choice in Dr. Booth’s Biology 100 courses designed to achieve that goal.

Student Training

Student training on the construction of concept maps included an initial training during a recitation session and then weekly homework assignments. These assignments were graded and returned to the students upon which students were given the opportunity to meet with their teaching assistant and receive feedback.

First-Day Training

During the first recitation session students were provided with a concept-map training worksheet (Appendix M). On this sheet they were provided instructions on the purpose of concept mapping, how to concept map, and how to write an appropriate linking phrase. They were then assigned two concept-mapping exercises where they were directed to fill in the blank concepts or blank linking phrases on a skeletal map. Each concept-mapping assessment contained concepts that possessed strong conceptual interrelationships. The concept-mapping exercises were assigned on a Thursday and due the following Monday. These exercises corresponded with the very chapters and lectures the students were assigned to read and process during that week.

Weekly Homework Assignments

Each Monday students were required to turn in their completed concept-mapping assignments at the end of class. Students also received their next concept-mapping assignment on that day. Each assignment consisted of two to three concept-mapping exercises. The first two assignments directed students to fill in the blanks on a skeletal map (see Figure 9). The third assignment directed students to construct a map from a list of concepts (see Figure 11). In this way students were exposed to two models of concept maps containing effective linking phrases between concepts before constructing their own concept maps using the C-mapping task.

The teaching assistants spent the next three days grading concept maps. These maps were graded using the open construct-a-map task scoring rubric. This task was chosen because of the relative ease of its use and because it was decided that if students were familiar with this scoring rubric they could easily transfer those mapping skills to the constrained construct-a-map task. The teaching assistants returned students' graded concept-mapping assignments and invited them to meet with their assigned teaching assistant to discuss the reason for missing any points. Students who met with their teaching assistant and corrected their concept map were given full credit for the assignment. This process continued throughout the course of the semester.

Meaningful Feedback

Prior to grading student concept maps the raters themselves completed the concept-mapping assignments. This was a change from the pilot study in that the raters generally had not created the maps themselves and therefore could not fully appreciate the subtle nuances students dealt with when constructing a concept map. Feedback given by the raters was more exact and meaningful because of two important factors. First, concept-mapping assignments were constructed with lists of strongly related concepts, thus facilitating the construction of meaningful links. Second, students became aware early on that constructing links between some pairs of concepts by their very nature requires more careful thinking as opposed to constructing other pairs of concepts.

With these two considerations in mind the teaching assistants graded the scaffolded (see Figure 9) and less scaffolded (see Figure 11) student concept map homework assignments. Students were invited to meet with their assigned teaching assistant during the course of the week to discuss the links that were not given full credit. If students took the time to engage in a discussion about the links on their map that were marked as incorrect, they were given full credit for the assignment. In this way students were motivated to take the opportunity to check their understanding of conceptual interrelationships with the teaching assistants.

CHAPTER 4: RESULTS

Research Question 1

Research question 1 was posed in an effort to determine the source of rating variability in the ratings for each of the two C-mapping tasks. In particular the intent of the study was to investigate the degree to which rating variability was due to dependable differences in students' ability to construct concept maps that depict important, accurate, complete, and relevant conceptual interrelationships (this represents desirable variance), and percentage due to any of the following sources of measurement error: (a) inconsistencies between raters; (b) inconsistencies within individual raters across rating occasions; (c) inconsistencies described by the three, 2-way interactions that can be estimated from the two-facet, fully crossed design; and (d) unexplained error that cannot be attributed to any of the identified sources. Specific results for each task on both midterm exams are reported in this chapter.

Exam 1: Task 1

The estimated variance components for each of the seven sources of variation in the ratings are reported in Table 6. The rows in the table provide several statistics associated with the possible sources of variation in the ratings that can be estimated from a two facet, fully crossed design with persons as the object of measurement. These statistics include the percent of the total variation contributed by each source of rating variability along with the standard error for each estimated variance component.

Variance Component for Persons

As shown in Table 6, the variance component for persons accounts for 66% of the variability of the ratings. Hence, two-thirds of the total variability in the ratings is

Table 6

Crossed Design G-study of Student Concept-map scores on Exam 1 Task 1

Source of Variation	Degrees of Freedom	Estimated Variance Components	Percent of Total Variation	Standard Error
Persons	23	20.1	66%	6.1
Occasions	3	0.0	0%	0.4
Raters	1	0.7	2%	1.5
PxO	23	0.5	2%	0.6
PxR	23	1.1	4%	0.8
RxO	3	2.1	7%	1.5
Residual	69	5.9	19%	1.0

explained by the person mean averaged across all four raters and both rating occasions. This variance in the estimated universe scores of individual students provides evidence that most of the variability is due to dependable differences in the mean map ratings of the 24 students. The 34% of the variability in the ratings not contributed by the object of measurement will be described in the rest of this section.

Variance Component for Rating Occasions

If the mean rating averaging across persons and raters from the first to second occasions is unchanged, then rating occasion variance component would be zero. As shown in Table 6, the variance component for rater occasion accounts for 0% of the variability of ratings. The mean rating for occasion 1 averaged across all raters and persons was 21.92 and the mean rating for occasion 2 was 21.90, yielding a difference of only .02 points between the two means. This result was somewhat surprising in that several of the raters reported reconsidering the deficiencies of the rubric and making modifications after the first occasion. In the final analysis, it appears that such a move did not influence error associated with the occasion facet.

Variance Components for Raters

As shown in Table 6, the variance component for raters accounts for 2% of the variability in the ratings. The mean rating for each rater averaged across all persons and all occasions for each rater is depicted in Table 7. The values in the second row of the table represent the deviation from the mean of all raters averaged across all persons and both occasions. Notice that the mean rating for rater 1 and 2 is slightly less then the overall rater average.

Person-by-Occasion Interaction

As shown in Table 6, the variance component for the person-by-occasion interaction accounts for 2% of the variability in the ratings. With a low relative percentage of the total variability, it would appear that the relative ordering of the students' mean ratings (averaged across the four raters) was consistent across the two rating occasions. However, the relatively small magnitude of this variance component indicates that this particular two-way interaction was not a major contributor to the error variance.

Table 7

Differences in Rater Means

	Rater 1	Rater 2	Rater 3	Rater 4	Grand mean
Mean Rating	21.3	20.2	23.0	23.1	21.9
Deviation from Grand Mean	-0.7	-1.7	1.1	1.2	0.0

Person-by-Rater Interaction

As shown in Table 6, the variance component for the person-by-rater interaction accounts for 4% of the variability. While comparatively low with regards to the object of measurement, this facet was relatively larger than the other sources of error. When this source of measurement error is relatively high, this indicates that the relative order of the mean rating for each student (averaged across both rating occasions) differs from rater to rater.

Rater-by-Occasion Interaction

The variance component for the rater-by-occasion interaction accounts for 7% of the total rating variability (Table 6). If this variance component is relatively high, then the relative order of the means of the four raters (averaged across all 24 students) was different on the first rating occasion compared to the second rating occasion. In other words a rater who is more stringent than other raters on the first occasion was more or less stringent in relation to those same raters on the second occasion.

Residual Variance Component

As shown in Table 6, the variance component for the unexplained error accounts for 19% of the variability of ratings. This variance component consists of the unique combination of P, R, and O facets and/or random events (Shavelson & Webb, 1991). The residual variance component contributed the second largest amount of relative variability in the ratings.

Exam 1: Task 2

Variance Component for Persons

The results of a G-study for student-concept-mapping scores on exam 1 task 2 are summarized in Table 8. The variance component for persons accounts for 92% of the variability in the ratings. This high percent of the variability of the ratings contributed by the object of measurement is highly unusual. The reasons for this unlikely result will be considered in the next chapter.

Error Representing Small Contributions to Total Variability

With the exception of person-by-rater and residual-variance components, the other variance components contributed little to the total variability in the ratings. The only variance components that contributed substantially to the total variation were the person-by-rater interaction and residual error.

Table 8

Crossed Design G-study of Student Concept-map Scores on Exam 1 Task 2

Source of Variation	Degrees of Freedom	Estimated Variance Components	Percent of Total Variation	Standard Error
Persons	23	80.3	93%	23.0
Occasions	3	0.0	0%	.0
Raters	1	0.9	1%	.9
PxO	23	0.2	0%	.2
PxR	23	2.6	3%	2.6
RxO	3	0.0	0%	.0
Residual	69	2.5	3%	2.5

Exam 2: Task 1

The results of a G-study for student concept-mapping scores on exam 2 task 1 are summarized in Table 9. As depicted in this table the person facet was relatively high accounting for 77% of the total variability, followed by the residual and the rater facet accounting for 11% of the total variability each.

Variance Component for Raters

As noted in Table 10, the mean rating for rater 2 was 3.6 points below the grand mean of all raters. This would indicate that rater 2 was much more stringent than the other raters.

Table 9

Crossed Design G-study of Student Concept-map Scores on Exam 2 Task 1

Source of Variation	Degrees of Freedom	Estimated Variance Components	Percent of Total Variation	Standard Error
Persons	23	42.0	77%	12.1
Occasions	3	0.0	0%	.1
Rater	1	5.9	11%	3.8
PxO	23	0.0	0%	.4
PxR	23	0.4	1%	.8
RxO	3	0.0	0%	.2
Residual	69	6.0	11%	1.0

Table 10

Differences in Rater Means

	Rater 1	Rater 2	Rater 3	Rater 4	Average
Mean Rating	26.4	22.5	28.1	27.2	21.9
Deviation from Grand Mean	0.3	-3.6	2.1	1.2	0.0

Residual Variance Component

As with the rater facet, the residual variance component also contributed 11% to the total variability in the ratings. Several factors that may have caused this component to be relatively large are considered in the final chapter.

Exam 2: Task 2

The results of a G-study for student concept-mapping scores on exam 2 task 2 are summarized in Table 11. As depicted in this table the object of measurement was relatively high accounting for 71% of the total variability, followed by the person-by-rater interaction accounting for 14%, the residual variance component accounting for 9%, and the rater facet accounting for 4% of the total variability in the ratings.

Person-by Rater-Interaction and Residual Variance Component

As shown in Table 11, the variance component for the person-by-rater interaction accounts for 14% of the variability of ratings. This would indicate that the relative ordering of the mean concept-map ratings for persons (averaged across both occasions) differed from one rater to another. Reasons for such variability will be considered in the chapter that follows.

Variance Component for Raters

As shown in Table 11, the variance component for raters accounts for 4% of the variability in the ratings. The mean rating averaged across all persons and all occasions for each rater is depicted in Table 12. Notice that the first two rater mean ratings were less than the overall rater average.

Table 11

Crossed Design G-study of Student Concept-map Scores on Exam 2 Task 2

Source of Variation	Degrees of Freedom	Estimated Variance Components	Percent of Total Variation	Standard Error
Persons	23	34.8	71%	10.6
Occasions	3	0.0	0%	0.1
Rater	1	2.0	4%	1.6
PxO	23	1.0	2%	0.6
PxR	23	6.8	14%	1.5
RxO	3	0.1	0%	0.2
Residual	69	4.3	9%	0.7

Table 12

Differences in Rater Means

	Rater 1	Rater 2	Rater 3	Rater 4	Average
Mean Rating	24.5	25.7	28.2	26.9	26.3
Deviation from Grand Mean	-1.8	-0.6	1.9	0.6	0

Research Question 2

Research question 2 was posed to consider how the reliability of the mean ratings of the students' conceptual understanding generated by one rater on one occasion compare across the two C-mapping tasks. Table 13 provides a comparison of each g and phi coefficient for ratings produced by one rater on one rating occasion for task 1 and 2 on exam 1. Likewise, Table 14 provides the same information for task 1 and 2 on exam 2. With the exception of the phi-coefficient for task 1 on exam 1, the reliability coefficients for relative and absolute decisions were higher than .70.

Table 13

G and Phi Coefficients for the Crossed Design Exam 1 Task 1 and 2

	Task 1		Task 2	
Type of Decision	Reliability	Standard Error	Reliability	Standard Error
Relative Decision	.728	2.7	.939	15.4
Absolute Decision	.659	1.9	.929	13.2

Table 14

G and Phi Coefficients for the Crossed Design Exam 2 Task 1 and 2

	Task 1		Task 2	
Type of Decision	Reliability	Standard Error	Reliability	Standard Error
Relative Decision	.867	6.5	.743	2.8
Absolute Decision	.772	3.4	.710	2.4

Research Question 3

Research question 3 was posed to consider how the reliability for each task would likely be increased or decreased by varying the number of raters or rating occasions. A D-study was therefore conducted to estimate how the changes described would increase or decrease the error variances and inversely the generalizability coefficients.

These projections were obtained by performing a D-study analysis on the variance components reported in Tables 6, 8, 9, and 11. The patterns from the data drawn from exam 1 task 1 and exam 1 task 2 reported in Figure 21 indicate that increasing the number of raters from one to two will have a greater effect on the reliability of the ratings than varying the number of occasions or increasing the number of raters from 2 to 3 or 3 to 4. Likewise, the patterns from data drawn from exam 2 task 1 and exam 2 task 2 in Figure 22 indicate that varying the number of raters from one to two on one rating occasion would provide the greatest increase in the reliability of the concept-map ratings at the most feasible cost.

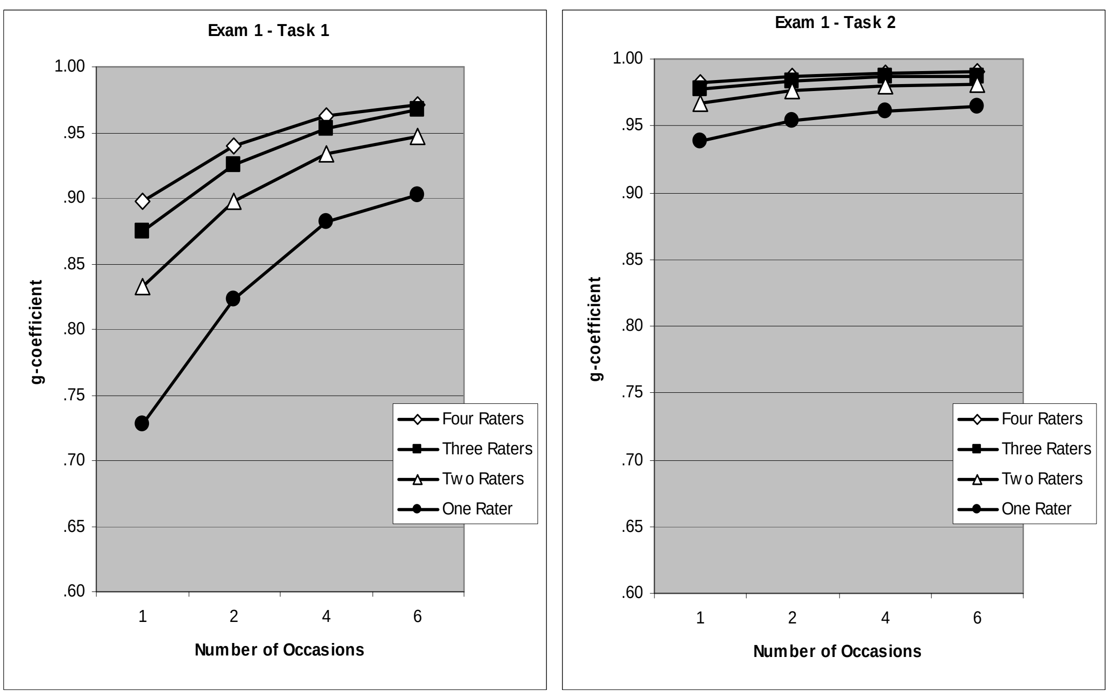


Figure 21. Projected reliability of relative decisions from exam 1 tasks 1 and 2.

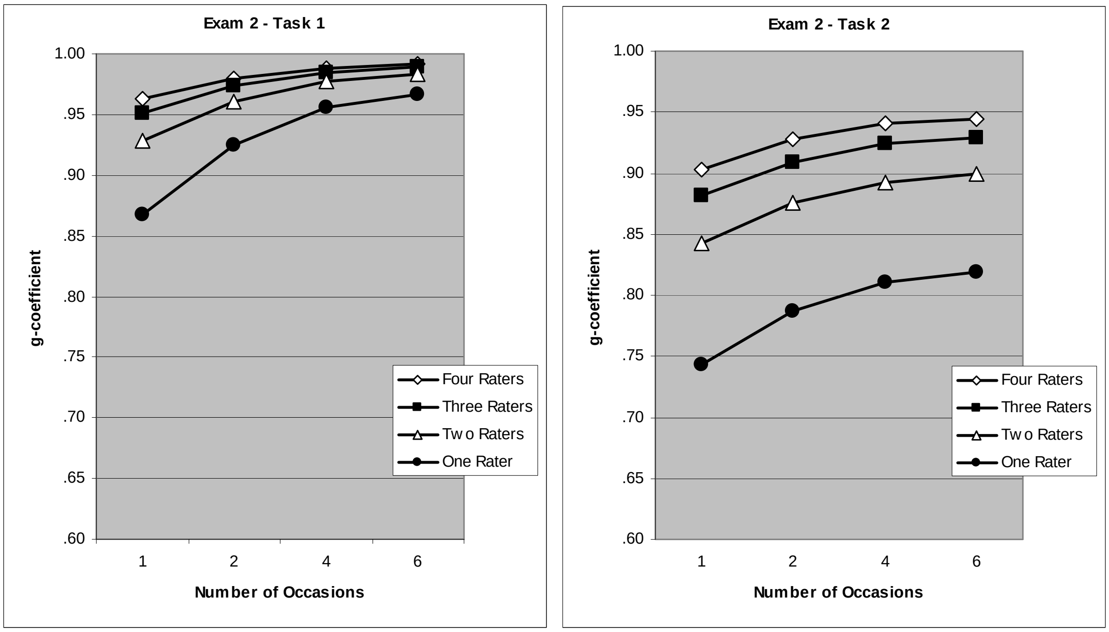


Figure 22. Projected reliability of relative decisions from exam 2 tasks 1 and 2.

Research Question 4

The results of the G-study are based on the assumption that every concept map constructed by every student would be rated by four raters on two separate rating occasions. Since such a design may not be feasible in more practical settings, other D-studies were performed to project the effect of using more feasible designs for collecting the ratings.

Most Feasible Design for Exam 1 Task 1

For exam 1 task 1, the most feasible nested design would include persons crossed with raters nested within occasions employing two raters instead of four (see the upper left panel in Figure 23). With this design a set of two raters rates all 24 concept maps on one occasion and another set of two raters rates all 24 concept maps on another occasion. The generalizability coefficient (used in relative decisions) for this design is projected to be .833 with a standard error value of approximately 2.7. The other designs reported in Figures 23 - 25 had a much higher percentage of total variability contributed by unexplained error. The relative error percentages of these more reliable rating designs also approximated those calculated in the fully crossed design, as noted in Table 6.

Most Feasible Design for Exam 1 Task 2

As will be explained in more detail shortly, exam 1 task 2 was something of an anomaly in that the students and raters were so familiar with constructing and rating the concepts in this task that the generalizability coefficient for this task was .939. Hence, it comes as no surprise that all of the other designs reported in Figures 23 through 25 produced similar reliability coefficients. Thus, all of the other designs under similar conditions that existed with exam 1 task 2 could be recommended as more feasible substitutes to a fully crossed design.

Most Feasible Design for Exam 2 Task 1

As was the case with exam 1 task 1 the person–by-rater within occasion design (see Figure 18) also would be the most feasible design to employ compared to the fully-crossed design without a decrease in the generalizability coefficient (see the lower left panel in Figure 23). The generalizability coefficient for two sets of two raters rating on separate occasions is projected to be .929 with a standard error of 5.7. The percentage of the total variability of the ratings contributed by the person facet would be 77%, while in the Px(R:O) design 72% of the total variability is contributed by the person facet. The contributions made to the total score variation by the other facets and interactions are evenly distributed.

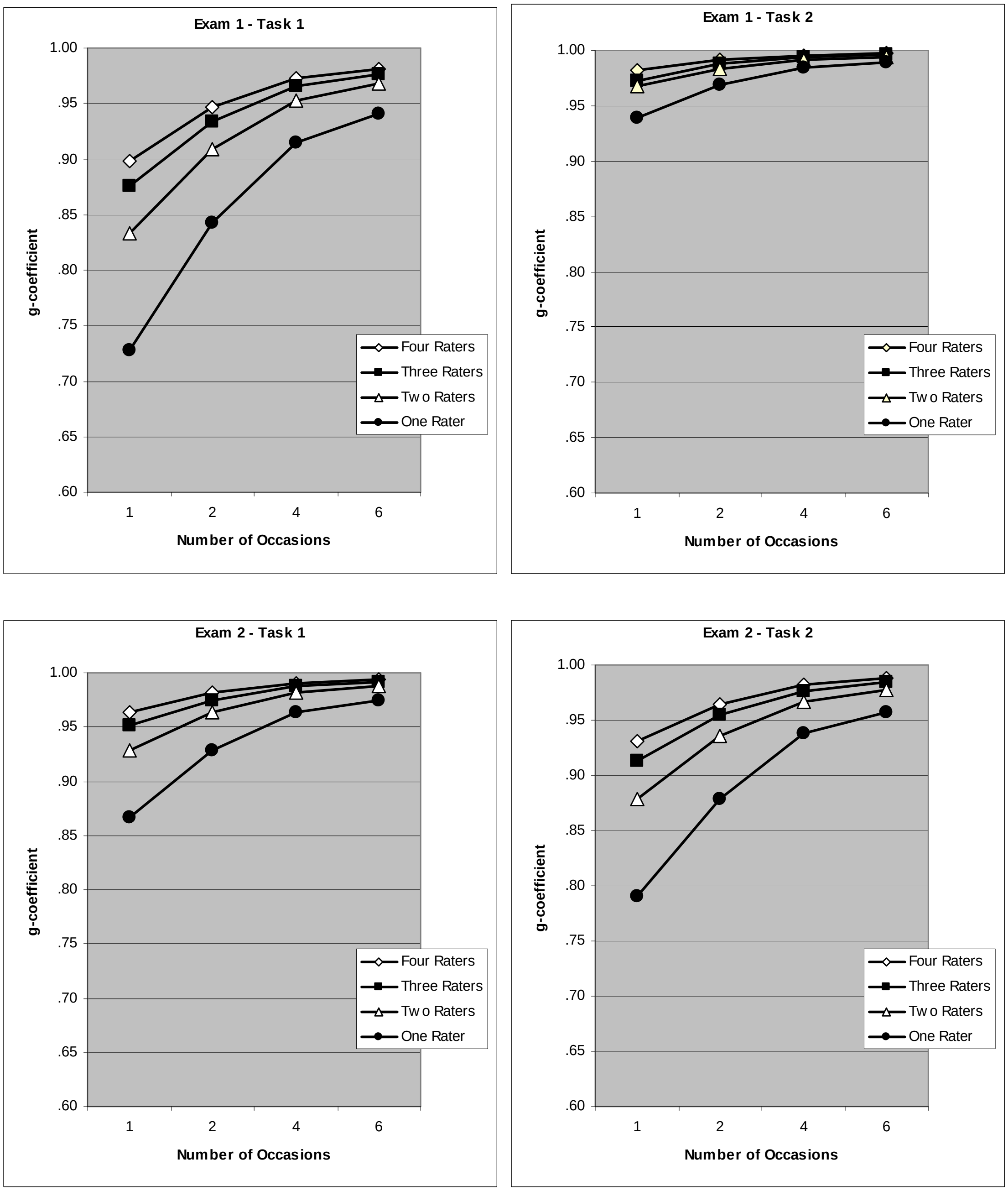


Figure 23. Projected reliability for person by two raters nested within occasion design.

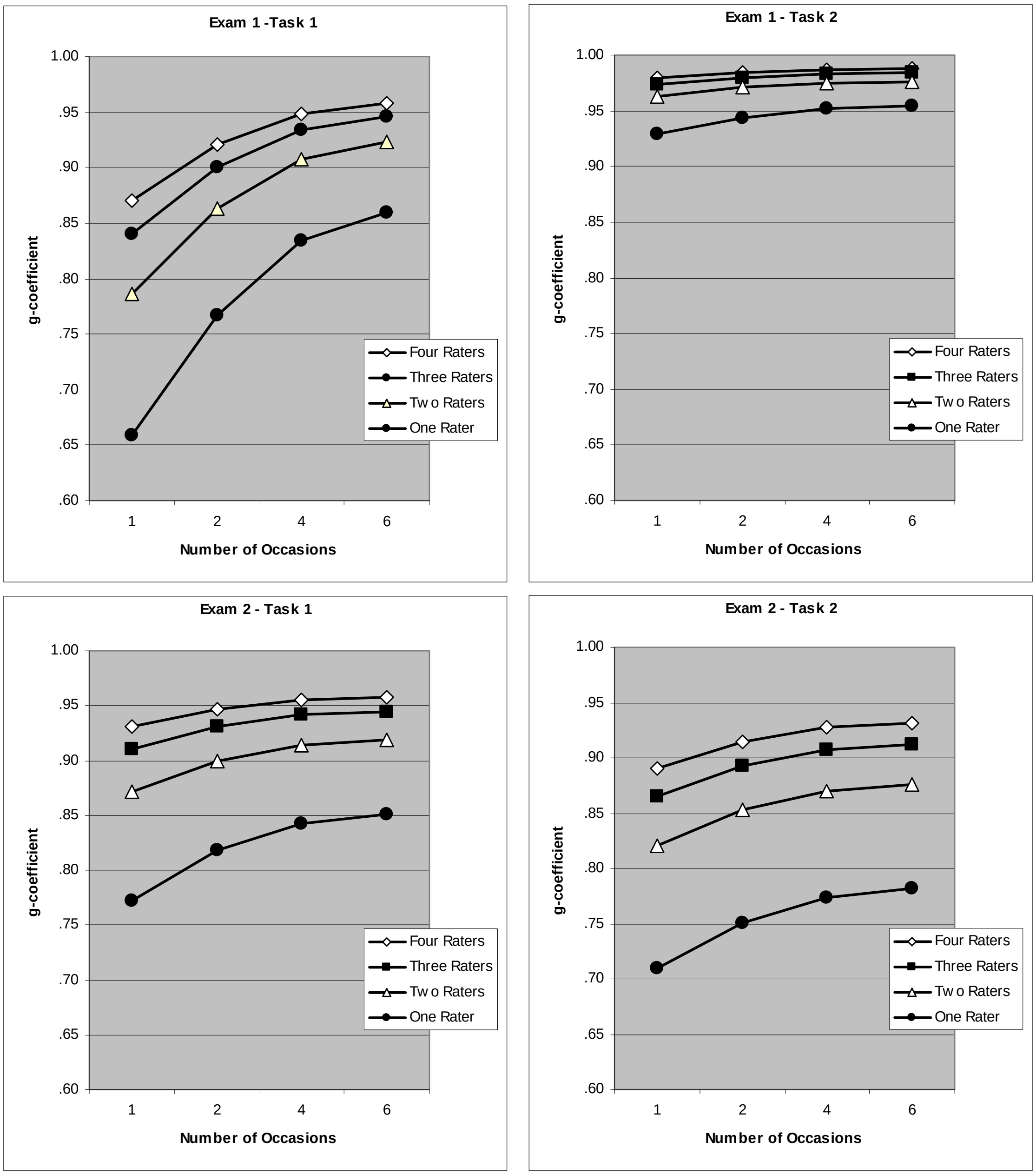


Figure 24. Projected reliability of two raters nested within person-by-occasion design.

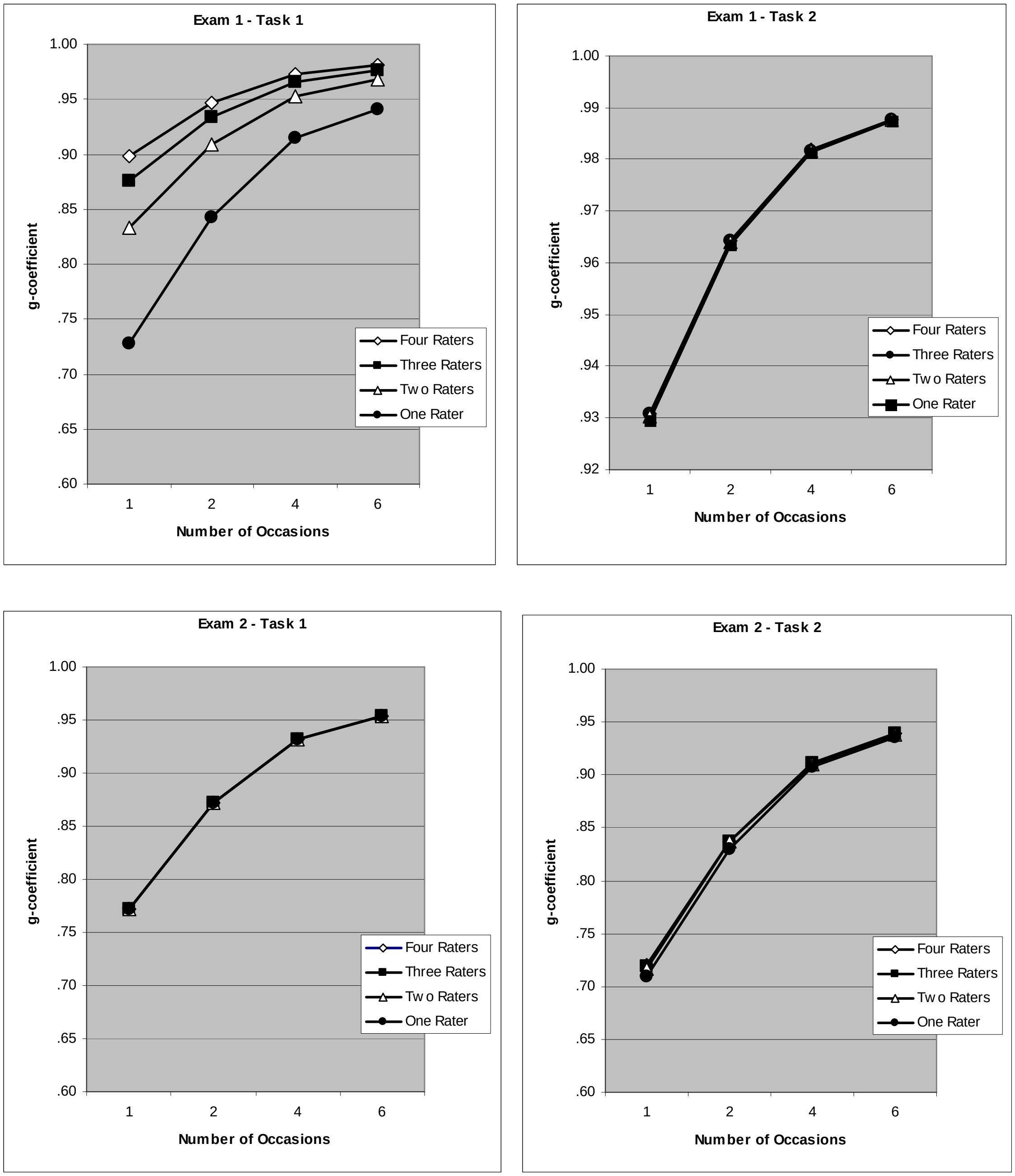


Figure 25. Projected reliability of four raters nested within person-by-occasion design.

Most Feasible Design for Exam 2 Task 2

The most feasible design for exam 2 task 2 is the person-by-rater within occasion design as was the case with task 1 on both exams. Here the generalizability coefficient would also only slightly decrease if two raters rated the concept maps instead of four (see the lower right panel in Figure 23). The generalizability coefficient (used in relative decisions) for this design is projected to be .843 with a standard error value of approximately 2.9.

Research Question 5

The fourth research question was posed to consider the degree to which concept-map ratings distinguish between students whose essays and/or interviews show evidence of important, accurate, complete, and relevant understanding of conceptual interrelationships and those students who do not exhibit this type of understanding for both C-mapping tasks.

Using a design where four raters rated essays and interviews on two occasions, all sets of criterion measure scores were found to be highly reliable with a relatively large amount of the total variability contributed by the object of measurement (see Table 15). The Pearson correlations computed between concept-map and other criterion measures are reported in (Table 16).

Proposition Similarity between Concept-Map and Criterion Measures

The section that follows describes the common conceptual relationships found across the C-mapping task maps and essays and as well as C-mapping task maps and interview transcripts for both tasks on both exams. These descriptions will help the reader to have a better sense of how students expressed themselves in some instances similarly, and in other instances differently, across these three assessments.

Table 15

Reliability Estimates for the Criterion Measures

Criterion Measure	G Coefficient (based on mean ratings for each student averaged across 4 raters on 2 occasions)	Percentage of Total Variability Attributed to the Object of Measurement
Essay exam 1 task 1	.951	76%
Essay exam 1 task 2	.903	63%
Essay exam 2 task 1	.986	73%
Essay exam 2 task 2	.986	71%
Interview exam 1 task 1	.802	46%
Interview exam 1 task 2	.847	55%
Interview exam 2 task 1	.992	81%
Interview exam 2 task 2	.986	79%

Table 16

Pearson Correlations between Concept-maps and Criterion Measures

	Essay Task 1	Essay task 2	Interview task 1	Interview task 2
Map task 1 exam 1	.66*		.63*	
Map task 2 exam 1		.62*		.62*
Map task 1 exam 2	.75*		.81*	
Map task 2 exam 2		.75*		.65*

* $p < .05$

Exam 1: Task 1

Concept maps and essays. Figures 26 and 27 depict the common propositions shared between a student's first essay and concept-map task from exam one. The common propositions found on this student's concept map and essay are *activation energy – enzymes*, *enzymes – competitive inhibitor*, and *enzymes – noncompetitive inhibitor*. As an example of a common response found on both measures, notice that on the concept map this student linked the concepts *activation energy* and *enzymes* with the phrase *is lowered by*. On the essay the student described this same relationship with the response: "enzymes are proteins used by the cell to speed up a reaction. This lowers the activation energy" (see Figure 27).

Notice that while the essay provides details like "Enzymes are proteins" or "used to speed up a reaction," these phrases are the antecedents for the word "This" in the next sentence. The student explains that "This" (enzymes and the process they impact) "lowers the activation energy" (see Figure 26). The relationship expressed in the essay and the concept map is analogous at the core. The more the conceptual relationships expressed by the students were similar on both their concept map and essay, the greater the rating correlations.

Concept maps and interviews. Figures 28 and 29 depict the common propositions shared between a student's first concept-map task and interview transcript and the first concept-map task from exam one. A concept-mapping task and an interview task provide students with different constraints, with regards to how they express their knowledge. In the interview the students were not directed to be concise in their responses, whereas with the concept mapping task brevity, accuracy, and completeness were emphasized. Notice

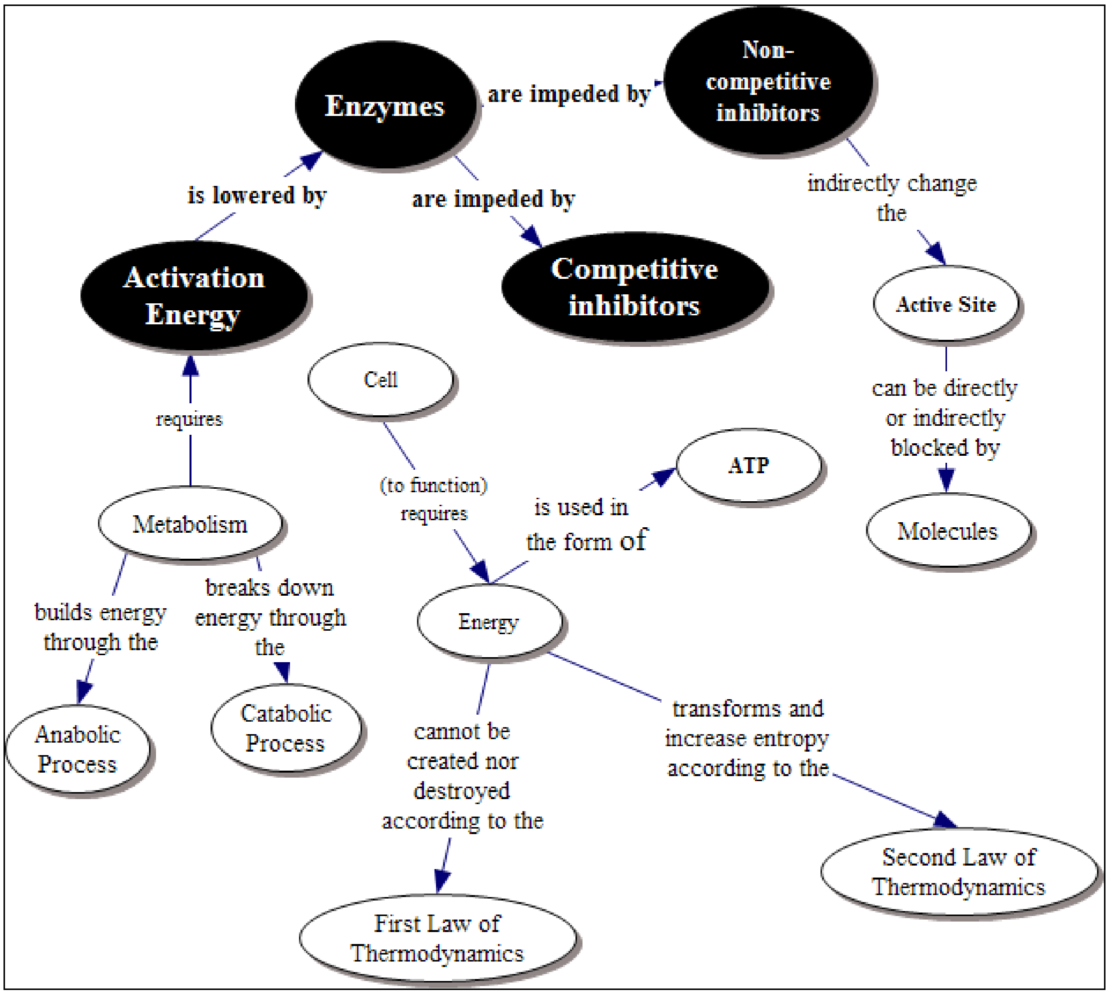


Figure 26. Student Y exam 1 task 1 concept map.

Note. Highlighted portions represent propositions found on this student's concept map and essay.

1) Explain how the following are inter-related: activation energy, enzymes, competitive inhibition, non-competitive inhibition.

Enzymes are proteins used by the cell to speed up a reaction. This lowers the activation energy and makes metabolic processes effective. There is a problem when an enzyme cannot join with its substrate. Competitive inhibition is when the active site is directly blocked by another molecule. Non-competitive inhibition, in contrast, blocks the substrate by indirectly changing the active site.

Figure 27. Student Y exam 1 task 1 essay.

Note. Highlighted portions represent propositions found on this student's concept map and essay.

that this student's responses depicted in Figure 28 express the relationship also found on the concept map between *enzymes* and *noncompetitive* and *competitive inhibitors* with the phrase "are impeded by." This would be considered an accurate, concise linking phrase between these two concepts. In the interview the student provides more information as follows:

> Enzymes join with the substrate at the active site in an ideal situation which would allow the enzyme to function. The problem is that sometimes inhibitors, competitive inhibitors would block the active site directly so that the substrate cannot join with the enzyme. There is also non-competitive inhibition where a molecule would block another part of the enzyme and would actually change the active site and so indirectly block the substrate. (see Figure 29)

Notice that the student expresses that ideally the enzymes would join with a substance called a substrate. This joining of enzyme and substrate occurs at the active site. The student further states that the enzyme's ability to function is compromised by a competitive inhibitor which blocks the active site directly. This relationship expressed between enzyme and competitive inhibitor can be subsumed under the linking phrase *are impeded by*.

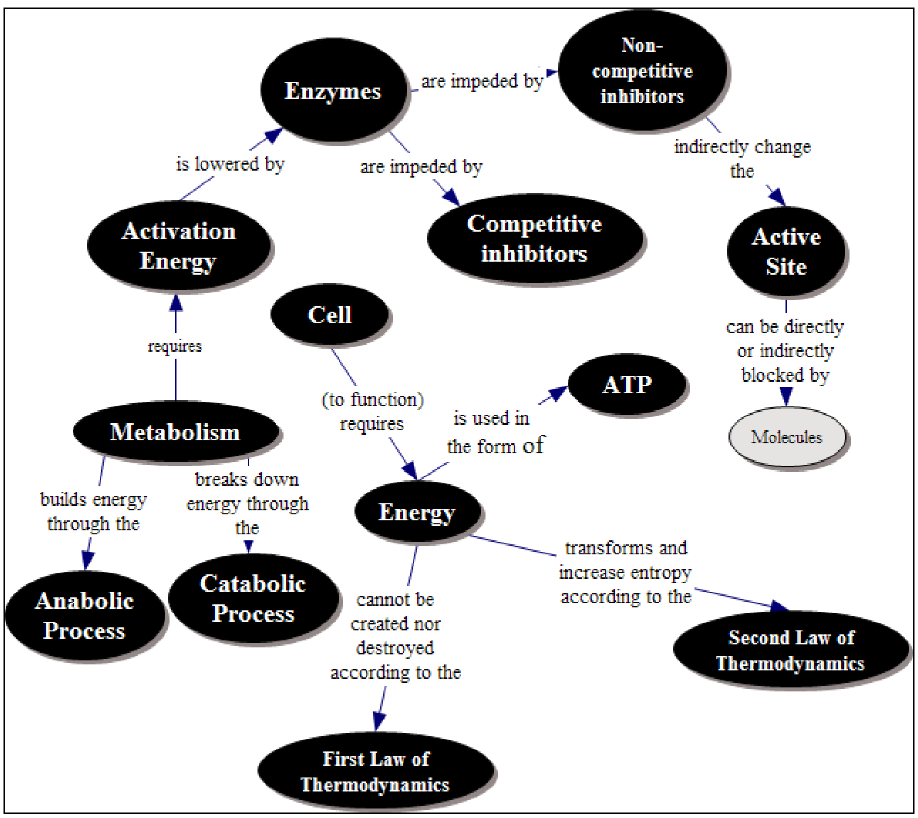


Figure 28. Student Y exam 1 task 1 concept map.

Note. Highlighted portions represent propositions found on this student's concept map and interview transcript

INTERVIEWER: Explain the difference between an anabolic process and a catabolic process.
STUDENT: An anabolic process is when it builds up on different things such as protein synthesis and catabolic is when destroys such as cellular respiration, it break things down.
INTERVIEWER: Explain the relationship between the following concepts: *ATP, CELL, & ENERGY*
STUDENT: A cell requires energy to function but it can't pull it directly from the substitutes such as where energy comes from. **Energy first has to be broken down into a usable form and that form is ATP.**
INTERVIEWER: How would you explain the relationship between: *ACTIVE SITE, COMPETITIVE INHIBITORS, ENZYMES, & NONCOMPETITIVE INHIBITORS*
STUDENT: Enzymes join with the substrate at the active site in an ideal situation which would allow the enzyme to function. **The problem is sometimes is that inhibitors, competitive inhibitors would block the active site directly so that the substrate cannot join with the enzyme. There is also non competitive inhibition where a molecule would block another part of the enzyme and would actually change the active site and so indirectly block the substrate.**
INTERVIEWER: Organize the following concepts hierarchically (from most general to least general) *(Hint: some may be at the same level). ANABOLIC PROCESS, CATABOLIC PROCESS, CELL, ENZYMES, & METABOLISM*
STUDENT: The most general I can see is the metabolism which is the process that uses both anabolic and catabolic process which would be next, and those work in a cell which means enzymes in order to perform this.
INTERVIEWER: Explain the relationship between: Activation Energy & Enzymes.
STUDENT: The cell requires activation energy in order to carry processes. The activation energy would be really high if it wasn't for enzymes. Enzymes help speed up the reaction which helps lower the activation energy so the process that is taking place is more efficient.
INTERVIEWER: How do the first Law of Thermodynamics and the Second Law of Thermodynamics impact the nature of energy?
STUDENT: The first law of thermodynamics says that energy cannot be created or destroyed and the second law is that energy transferred increases the entropy of the universe. So, the 2 processes are involved; obviously they relate to energy. They utilize the idea of energy and allow it to be used in all processes to be used as matter. It would never be destroy or diminished, it would only be simplified and spread out in the universe.
INTERVIEWER: Where, specifically, do Glycolysis, Krebs Cycle, and Oxidative Phosphorylation take place?
STUDENT: Glycolysis takes place in the cytoplasm, krebs cycle works through the mitochondria and oxidative phosphorylation is in the mitochondria membrane.

Figure 29. Student Y exam 1 task 1 interview transcript.

Note. Highlighted portions represent propositions found on this student's concept map and interview transcript.

Exam 1: Task 2

Concept maps and essays. Figures 30 and 31 depict the common propositions shared between a student's second essay and concept-map task from exam one. These common propositions include, *ATP – Terminal Phosphate* and *ATP – ADP*. To illustrate how the expressions between the two measures were similar, in the concept map a student expressed the relationship between ATP and Terminal phosphate with the phrase: "releases energy by breaking the bond of" (see Figure 30). The student

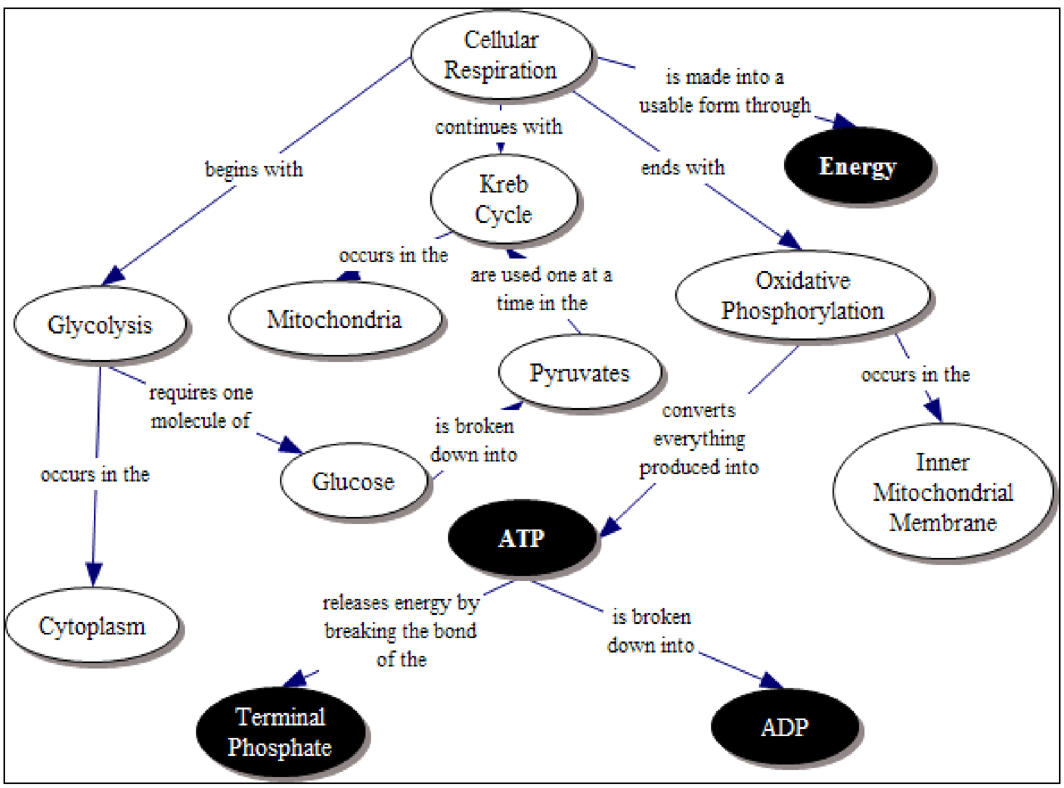


Figure 30. Student Y exam 1 task 2 concept map.

Note. Highlighted portions represent propositions found on this student's concept map and essay.

2) Explain how the following are inter-related: ATP, ADP, Energy, Terminal Phosphate.

The body cannot directly use energy from the food it gets. It must be broken down and converted to ATP. An ATP molecule stores energy. To release that energy, the bond of its terminal phosphate must be broken. When it is, energy is released and the ATP has now been broken down into ADP.

Figure 31. Student Y exam 1 task 2 essay.

Note. Highlighted portions represent propositions found on this student's concept map and essay

expressed the same relationship on the essay with the following: "An ATP molecule stores energy. To release that energy, the bond of its terminal phosphate must be broken" (see Figure 31).

Concept maps and interviews. Figures 32 and 33 depict the common propositions shared between a student's second concept-map task and interview transcript from exam one. Notice that this student concisely expresses the relationship on the concept map between glycolosis and glucose concisely with the phrase "requires one molecule of" (see Figure 32). This would be considered an accurate linking phrase between these two concepts. Likewise the student links glucose and pyruvate with the linking phrase "is broken down into" (see Figure 32). In the interview the student provides more information as follows: "Glycolysis first breaks down the glucose molecule which moves forward to the Pyruvates which are used then in the Kreb Cycle" (see Figure 33).

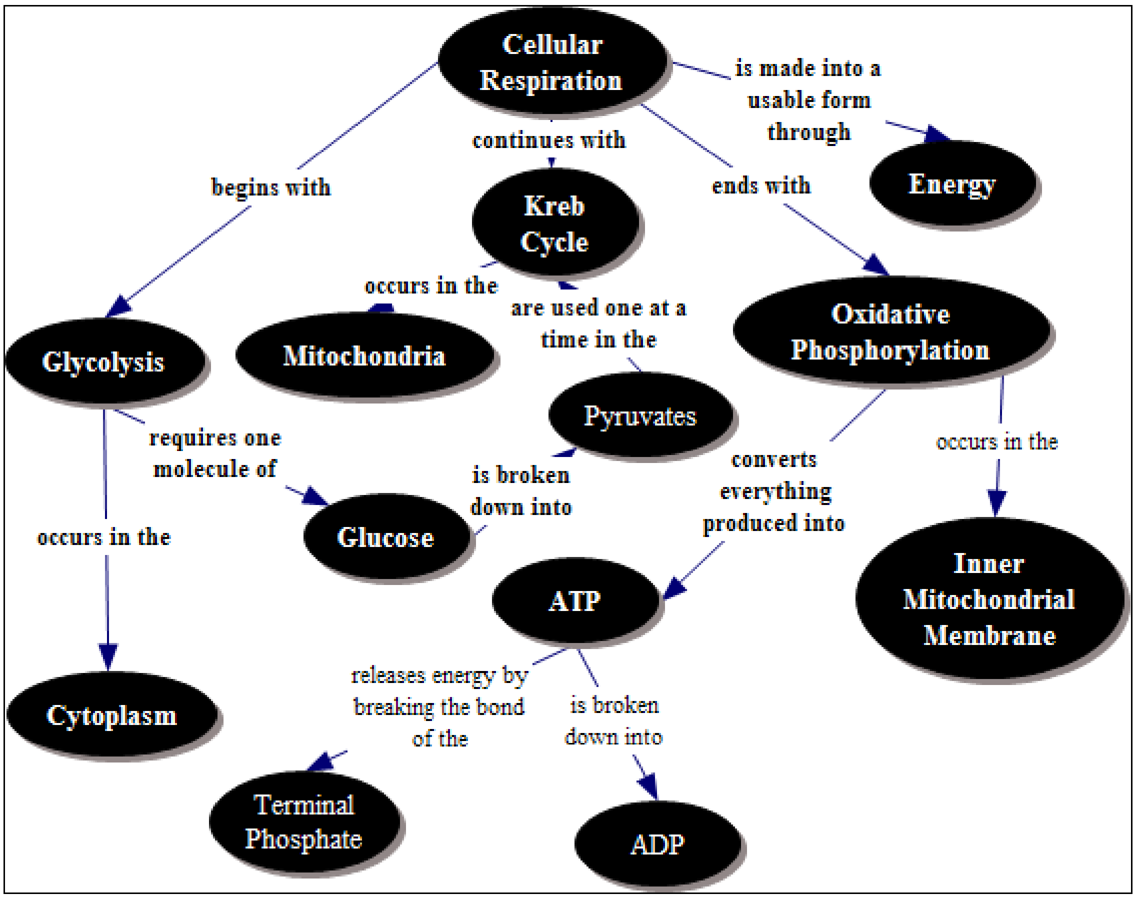


Figure 32. Student Y exam 1 task 2 concept map.

Note. Highlighted portions represent propositions found on this student's concept map and interview transcript.

INTERVIEWER: Where, specifically, do Glycolysis, Krebs Cycle, and Oxidative Phosphorylation take place?
*STUDENT: **Glycolysis takes place in the cytoplasm, krebs cycle works through the mitochondria and oxidative phosphorylation is in the mitochondria membrane.***
INTERVIEWER: How do Glycolysis, Kreb Cycle, and Oxidative Phosphorylation relate to one another?
*STUDENT: They relate to each other because all of them involve eventual creation of ATP. **Glycolysis first breaks down the glucose molecule** which moves forward to the **Pyruvates which are used then in the Kreb Cycle;** each of these cycles creates as small amount of ATP and the also NADH and FADH too. These final substances and then taken to **oxidative phosphorylation and turn into a greater amount of ATP.***
*INTERVIEWER: How do they differ from one another?STUDENT: Glycolysis is an anaerobic process and the Kreb cycle is aerobic. I am uncertain of Oxidative phosphorylation. But the largest difference would be **that oxidative phosphorylation** takes the molecules created by the other two and it is able to turn that into ATP because the **Kreb cycle** can only rotate one Pyruvate at a time, and **Glycolysis is just kind of the precursor**.*
INTERVIEWER: What role does Pyruvate play in Cellular Respiration?
*STUDENT: **The Pyruvates come from the glucose. The 6 carbon glucose that was broken down in Glycolysis and turn into the preparatory step.** The Pyruvates are broken down one after another into a Acytal COE and each Pyruvate is then sent to the Kreb cycle or it is broken down into NADH and FADH.*
INTERVIEWER: What role does Glucose play in Cellular Respiration?
STUDENT: Glucose is the main component used in cellular respiration is the shaver which contains the original energy but it cannot be used and so that glucose is effectively broken down so it can be converted into ATP used for cellular processes.
INTERVIEWER: Explain the relationship between: ADP, ATP, Terminal Phosphate, & Energy
*STUDENT: ATP is the way in which energy is able to be stored. In order for that energy to be released and used, the **terminal phosphate or the last phosphate on an ATP molecule has the final bond there and the terminal phosphate bond breaks off which releases the energy and simplifies ATP into ADP.***

Figure 33. Student Y exam 1 task 2 interview transcript.

Note. Highlighted portions represent propositions found on this student’s concept map and interview transcript.

Exam 2: Task 1

Concept maps and essays. Figures 34 and 35 depict the common propositions shared between a student’s first concept-map and essay task from exam two. Notice that the common propositions found on this student’s concept map and essay include, *transcription – translation, translation – proteins, proteins – amino acids, codon – mRNA, anti-codon – codon, tRNA – anti-codon, and amino acid - tRNA.* Several of the same propositions read almost identically on both the concept map and the essay. For example, the relationship on the concept map between transcription and mRNA reads, "Transcription is the process of copying DNA information onto mRNA" (see Figure 34). In the essay the same relationship reads, "Transcription is the process of copying DNA to a single strand of mRNA" (see Figure 35). Other propositions express the same idea but in different ways as is evident in the following relationship expressed between codons and anti-codons on the concept map: "Anti-codon matches up with its complementary codon" (see Figure 34). On the essay it reads, "This tRNA has anticodons which match up with the mRNA codons. (Codons are a sequence of 3 nucleotides on mRNA. Anti-codons are their complements found on tRNA)" (see Figure 35).

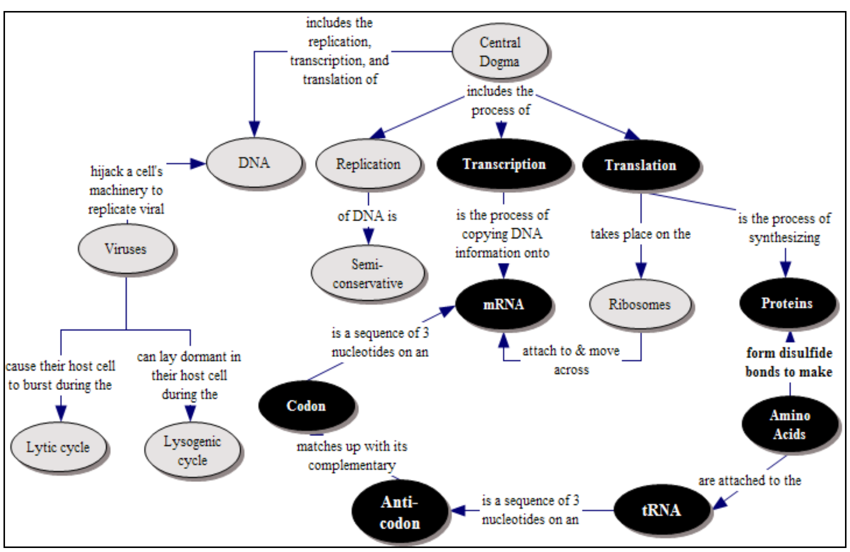


Figure 34. Student Z exam 2 task 1 concept map.

Note. Highlighted portions represent propositions found on this student's concept map and essay.

2) Explain how the following are inter-related: Anti-codon, Protein, Transcription

Transcription is the process of copying DNA to a single strand of mRNA. Transcription begins with binding and initiation, in which the RNA polymerase finds the initiation site in the promoter region on the DNA and then begins the process of elongation. The DNA is copied to the mRNA during this step. Termination follows, in which the mRNA separates form the DNA and the DNA winds back together. Since DNA never leaves the nucleus, transcription occurs so that the mRNA can take the genetic information to the ribosome in the cytoplasm. The process of translation can then occur, during which proteins are synthesized. The mRNA attaches to the small ribosomal subunit. A tRNA comes bring in attached amino acids with it. This tRNA has anticodons which match up with the mRNA codons. (Codons are a sequence of 3 nucleotides on mRNA. Anti-codons are their complements found on tRNA.) The mRNA, tRNA, and small ribosomal unit attach to the large ribosomal unit, which has the P & A sites. As the ribosome move down the mRNA strand, amino acids (brought by tRNA) form peptide bonds as they move through the P & A sites. These chains of amino acids form proteins. So transcription must occur so that mRNA can take the copied DNA information to the ribosomes. tRNA then matches its anti-codons with mRNA codons, and brings amino acids which bond to make proteins

Figure 35. Student Z exam 2 task 1 essay.

Note. Highlighted portions represent propositions found on this student's concept map and essay.

Concept maps and interviews. Figures 36 and 37 depict the common propositions shared between a student's first concept-map and interview task from exam two. These propositions include the same relationships expressed in the student's concept map and essay with additional propositions such as, *viruses – lytic cycle, viruses – lysogenic cycle* and *viruses – DNA.* For example, on the map the relationship between anticodon and codon reads, “anti-codon matches up with its complementary codon” (see Figure 36). The interview transcript reads, “the anticodon on the tRNA and the codon on the mRNA complement each other” (see Figure 37). However notice that some expressions vary from concept map to interview. The relationship expressed between viruses and lysogenic cycle on the concept map read “viruses can lay dormant in their host cell during the lysogenic cycle” (see Figure 36). However, in the interview transcript it reads, “In the lysogenic cycle the viral DNA is incorporated into the chromosomes and so replication occurs and so the viral DNA is replicated” (see Figure 37). Notice that the relationship on the concept map focuses on the dormant nature of this cycle whereas in the interview transcript the emphasis is on the replication of the viral DNA.

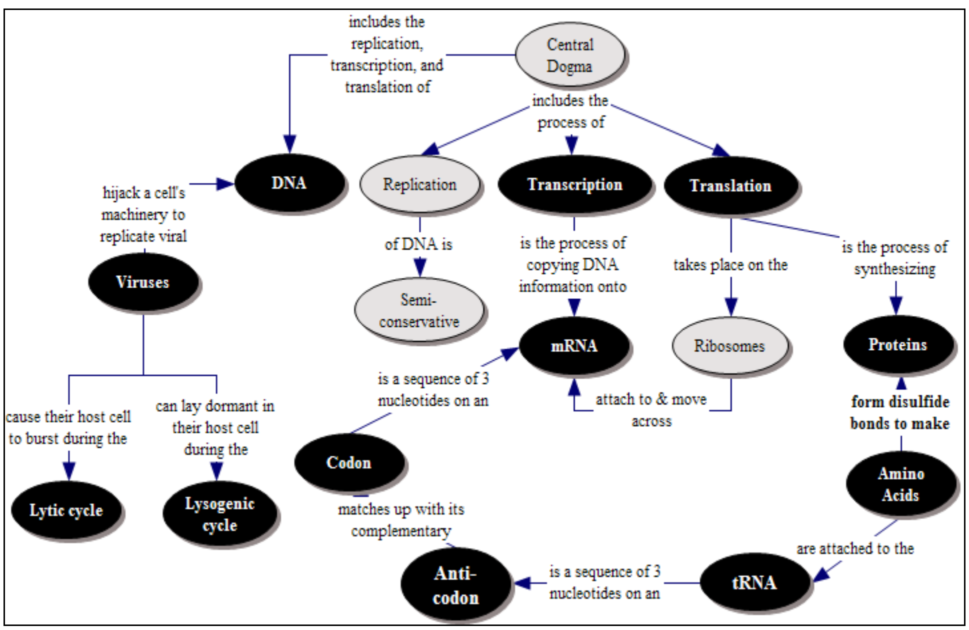


Figure 36. Student Z exam 2 task 1 concept map.

Note. Highlighted portions represent propositions found on this student’s concept map and interview transcript

INTERVIEWER: What is the connection between tRNA and a codon?
STUDENT: ***A codon is found on mRNA*** *and mRNA attaches with tRNA during translation and tRNA,* ***there is an anticodon and so the anticodon on the tRNA*** *and the* **codon on the mRNA complement each other** *and they are all attached during translation.*

INTERVIEWER: What role does mRNA play in the central dogma?
STUDENT: ***mRNA is made through the transcription process*** *and the mRNA is able to go out of the nucleus into the cytoplasm and* ***translate the DNA and make proteins****.*

INTERVIEWER: How are amino acids important to the process of translation?
STUDENT: Amino acids are brought by the tRNA and during translation the ***amino acids are linked together to form a pepti-bond and make a protein.***

INTERVIEWER: What role do anti-codons play in the production of proteins?
STUDENT: ***Anti codons are found on tRNA****. The tRNA during translation brings the amino acids and so the anti-codons complement the codons on mRNA and* ***they are all attached together and a pepti-bond is made from the amino acids and it makes protein.***

INTERVIEWER: How does replication effect the lysogenic cycle versus the lytic cycle?
*STUDENT****: In the lysogenic cycle the viral DNA is incorporated into the chromosomes and so replication occurs and so the viral DNA is replicated*** *and put into new cells and so is able to get to a lot more cells and attach them faster than the* ***lytic cycle.***

Figure 37 Student Z exam 2 task 1 interview transcript.

Exam 2: Task 2

Concept maps and essays. A Pearson correlation between the second concept-map and essay tasks on the second exam could not be computed because of a particular confound that arose during the course of the study. Therefore, a correlation was computed between a composite of essay and interview propositions and similar propositions also constructed on the concept map.

On the second essay task on the second midterm exam students were directed to make connections between the concepts *anti-bodies*, *exotoxins*, and *macrophages*. As was the case for task one on exam two these concepts are actually not directly related with one another but require the students to add other concepts in the essay in order to make the logical connections. The idea was that by directing the students to make connections between the concepts antibodies, exotoxins, and macrophages, students would have to respond with at the very least the concepts: gram positive bacteria, antigens or pathogens, B cells, and humoral immunity. It was thought that the more thorough answers would likewise include the concepts: gram negative, exotoxins, and potentially peptidoglycan.

After student responses were collected, it was found that the majority of the students included some but not all of the key additional concepts. This was probably a result of an inadvertent error committed in the development of the exam. Those in charge of developing the exam forgot to add this task. As a result none of the students answered the second essay task while the exam was in session. An effort was made to overcome this oversight by having the students complete the essay during the last 15 minutes of class three days later. Students who otherwise might have taken more time to answer the question more thoroughly may have been impacted by both the time constraint and the surprise that they were still taking an exam they thought they had already completed. The time constraints, therefore, potentially made it less likely for students to add the additional required concepts.

With this confound in mind the author decided to not correlate the concept-map and essay scores, but to create a composite score combining those connections made on the concept map with those made on both the essay and interview transcript.

Concept maps and interviews. Figures 38 and 39 depict the common propositions shared between a student's second concept-map task and interview transcript from exam two. These propositions include the same paired conceptual relationships from the essay with additional links between, *humoral – antibodies, cell mediated – T lymphcytes, gram positive* and *negative – peptidoglycan.* On the concept map, the student expressed the relationship between gram positive bacteria and peptidoglycan with the phrase, "Have many layers of" (see Figure 38). They also expressed the relationship between gram negative bacteria and peptidoglycan with the phrase, "Have one layer of" (see Figure 38). This same relationship was expressed on the student's interview with the following phrase: "Gram positive has many layers of peptidoglycan and then the gram negative has a plasma membrane and one layer of peptidoglycan" (see Figure 39).

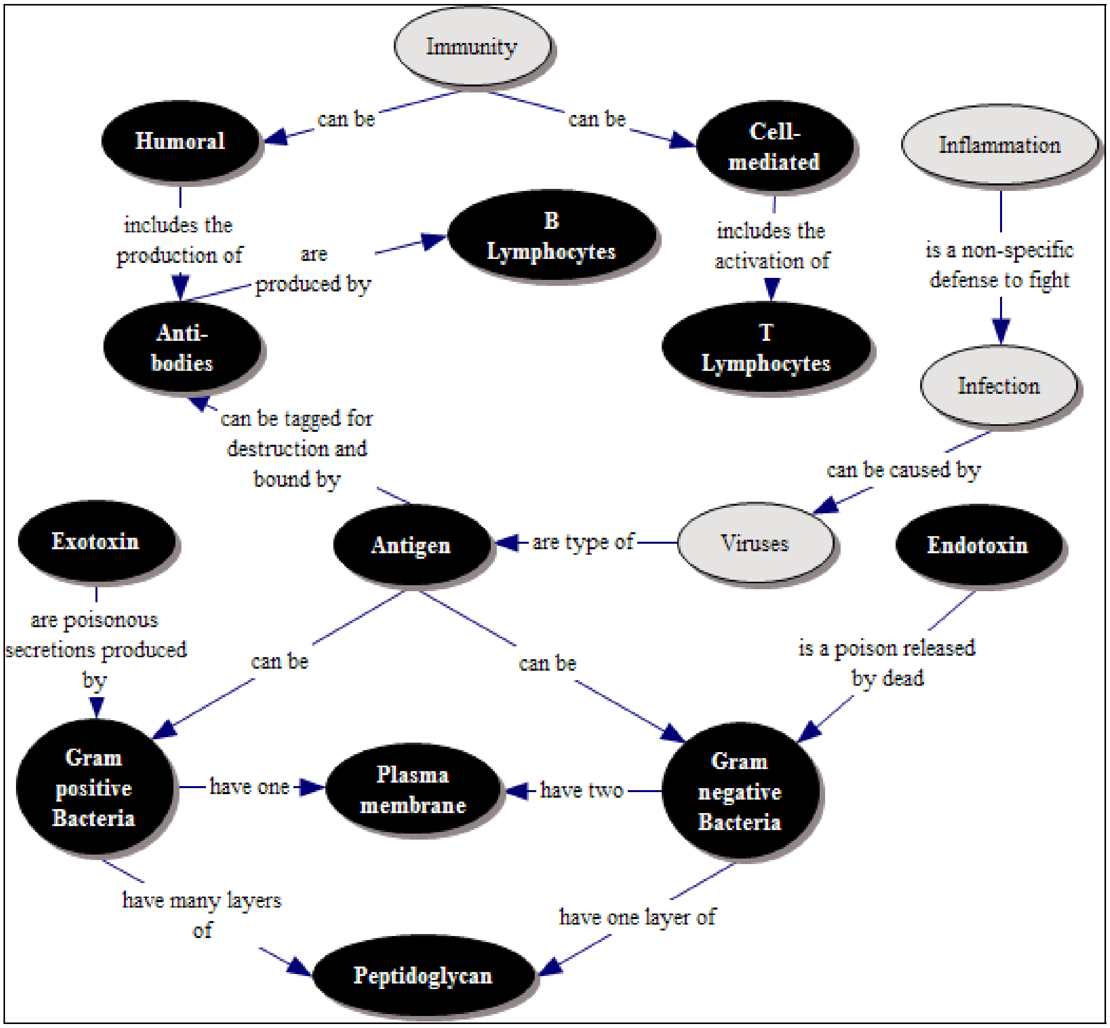


Figure 38. Student Z exam 2 task 2 concept map.

INTERVIEWER: What is the difference between cell-mediated and humoral immunity? Explain those differences in as many ways as you can.
STUDENT: **Cell-mediated immunity is with actually attacking the antigen that cells send T limphosites** out to actually attack and engulf, in fagotysosis, the antigen and destroy it. And in **humoral immunity there are antibodies that are made by B limphosite** and these antibodies are sent out to tag the antigens and then ???sites are able to go and destroy those.
INTERVIEWER: Describe the difference between gram positive and gram negative bacteria. What causes these differences?
STUDENT: **Gram positive bacteria** stains purple and it has a plasma membrane and one peptidoglycan layer and it is exotoxic and the gram negative is…stains pink. Oh, actually I messed . . . the **gram positive has many layers of peptidoglycan and then the gram negative has a plasma membrane and one layer of peptidoglycan** and then another plasma membrane and lippopolysaccharides on top of it. And it stains pink and **the gram negative is also endotoxic**. It is how much the die they absorb. So, the gram positive absorbs more die than the gram negative. Maybe it is because the peptidogycan layers absorb more and the more peptidogycan it has the more it absorbs.
INTERVIEWER: Describe the difference between active & passive immunity.
STUDENT: Active immunity would be, like you get the chicken pox or something and your body fights it off and builds anti-bodies against it and so next time you get that you are ready to fight it off and so you don't get a really bad infection again.
And passive would be like when you are born, like antibodies get transported through the placenta to the baby or through the mother breast's milk. And you can have either artificial immunity or you can have natural. So, you can have artificial passive or active and you can have natural passive or active.
INTERVIEWER: Why are there more macrophgages and anti-bodies at the site of inflammation?
STUDENT: Because when you are injured then you have increased phospoho and that increased phosphor would bring macrophgages and it can help fight that off.

Figure 39. Student Z exam 2 task 2 interview transcript.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

In this chapter a discussion of the results of the study is offered along with a description of the contributions made to the field of concept-mapping assessment research as well as recommendations for future studies.

Research Question 1

Object of measurement

The object of measurement was the largest contributor to total rating variability on both tasks. A relatively large amount of variance contributed by the object of measurement is considered to be desirable in that it represents rating variability not influenced by measurement error but person or student ability. This finding indicates that an appreciable proportion of what caused the scores to vary was influenced by variability in students' abilities to express conceptual interrelationships.

Constrained C-mapping Task

As reported in the previous chapter the percentage of rating variability contributed by the object of measurement on the constrained C-mapping task was 66% on the first exam and 72% on the second exam. These results appear to indicate that penalizing students for inaccurate propositions while simultaneously accounting for proposition choice did not produce an undo amount of measurement error.

Open C-mapping Task

The percentage of rating variability contributed by the object of measurement on the less-constrained or open C-mapping task was 93% on the first exam and 71% on the second exam. It appears that encouraging students to add relevant concepts to their concept maps while simultaneously accounting for proposition choice did not introduce a relatively large amount of measurement error either. What is unusual about these results is the inordinately high percentage contributed by student ability on the first task. While such a result is not impossible, it is improbable. In general, rater-mediated assessments that measure complex cognitive processes do not produce such high relative rating variability associated with the object of measurement. Two hypotheses are posited for this unusually large contribution to total rating variability on the first exam.

First, the rubric used on this task was the same rubric raters had used previously to rate the weekly homework maps. Thus they were familiar with it by the time they used it to rate the second concept-mapping task on the first exam. Rater familiarity with this rubric may have resulted in a decrease in measurement error across all facets of rating on this particular task compared to the first task where raters were required to consider the addition of a -.5 level to the rubric.

A much more plausible hypothesis is that the previous homework assignment contained essentially the same list of concepts as did the concept-map assessment on the first exam. Students were given master maps along with their returned graded assignment so as to compare their responses with the criterion map. The list of concepts for this assignment, along with those listed in task 2 on exam 1, are provided in Table 17. Notice that with the exception of the concept *organisms* the lists of concepts are the same.

Other Sources of Measurement Error

Rater Error

Rater error appeared to be a function of raters deciding when and when not to give students the benefit of the doubt when the propositions expressed were unclear.

Table 17

Concept List Comparison

List of concepts for Lecture 7 homework assignment	List of concepts exam 1 task 2
ADP	ADP
ATP	ATP
Cellular Respiration	Cellular Respiration
Cytoplasm	Cytoplasm
Energy	Energy
Glucose	Glucose
Glycolysis	Glycolysis
Krebs Cycle	Krebs Cycle
Inner Mitochondrial Membrane	Inner Mitochondrial Membrane
Mitochondria	Mitochondria
Organism	Oxidative Phosphorylation
Oxidative Phosphorylation	Pyruvates
Pyruvates	Terminal Phosphate
Terminal Phosphate	

This may have been less of an issue if one of the learning outcomes of the course had been for students to develop the specific skills of constructing important, accurate, complete, and relevant propositions.

As this was not the case the raters and hence the students placed varying degrees of emphasis on these scoring elements. Another factor that increased rater error initially but was less of an issue in later rating sessions, was the scoring of linking phrases that did not represent an understanding of new material taught in the course. For example, the concepts *cell* and *molecules* were two concepts from the list of concepts on the first task of the first exam. Several students constructed the proposition, *cell is made up of molecules*. While a true statement in and of itself, this proposition adds little to the understanding of the map topics that were catabolic and anabolic processes. This example comes from the first task; however, it appears to have been more of an issue on the second task. In retrospect, it appears that the rater training did not provide clear enough direction at the outset of the study to assist the raters in developing a working understanding of the rating elements represented in the rubric. This understanding evolved with practice becoming less of an issue in subsequent rating sessions.

Person-by-rater Interaction

Error associated with the person-by-rater interaction seemed to be a result of similar issues detected by the rating variability contributed by rater error. It would seem that the refinements in rater understanding and use of the rating criteria that developed between occasions did not impact the occasion facet but may have impacted the person-by-rater interaction. This would indicate that as each rater internalized their own clarifications of the rating criteria they did so in a way that caused the concept-map rating rank order to be different from rater to rater.

Error contributed by the rater-by-occasion interaction appeared to be a function of raters developing nuanced understandings of student expressions of conceptual interrelationships over time. However, instead of raters as a group becoming equally more or less stringent in their ratings, some raters became more stringent while others became more lenient. It appears that during the first task on the first exam raters were trying to feel their way to a coherent understanding of how to use the rubric to rate propositions. As this understanding became more stable, the magnitude of the rater-by-occasion interaction diminished dramatically.

Finally, residual or unexplained error generally contributed in the double-digit percentages to the total variability across exams and tasks. Rater fatigue was potentially one factor along with the fact that raters tended to tighten up their understanding of the criteria as they progressed through the rating session.

Contributions to the Field

To put these findings in perspective the only other published studies that have reported total variation of ratings contributed by the object of measurement were McClure et al. (1999) and Yin and Shavelson (2004). In the case of the study conducted by McClure et al. (1999) the generalizability coefficients of six scoring methods were compared using a person-by-rater fully crossed design. For each of the six scoring methods the object of measurement accounted for 15%, 27%, 33%, 35%, 55%, and 65% of the total rating variation. The study conducted by Yin and Shavelson compared two concept-mapping tasks using a person-by-proposition-by-format fully crossed design and a person-by-proposition-by-occasion fully crossed design. In all four cases, the percentage of the total rating variability contributed by the object of measurement was 5.9%, 8.1%, 10.4%, and 18.6%. In each case by far the greatest contributor to the total rating variation was unexplained error.

While there is no definitive explanation for the small percentage of variance associated with the object of measurement reported in these studies, one possible hypothesis should be considered. Unlike the studies previously cited, the teaching assistant/raters in this study had a developed sense of student abilities with the material in that they attended every one of their classes and recitation sessions along with grading all of the homework. In this way they gained a thorough understanding of not only the material on which the students were instructed but their level of understanding of that material. Likewise, the raters became very familiar with the rating rubric as they rated concept-mapping homework assignments as well as exam test items. The combination of these factors may have been instrumental in generating such high relative variance associated with the object of measurement.

Along with the strengths of both rubrics in assisting raters to produce reliable and valid ratings, several weaknesses became apparent as well. Raters reported that during the rating sessions when a student's response was unclear, they tended to guess what they thought the students meant. All four raters indicated that if a student constructed several correct propositions adjacent to a proposition that was unclear they generally gave the student the benefit of the doubt, awarding them full points. This halo effect was not uniform between or within raters in every instance and no doubt represented a source of measurement error.

Another issue impacting the reliability of the ratings arose from the requirement on the first task to penalize students with negative points for inaccurate propositions. In several instances a student constructed what otherwise would have been an important, accurate, complete, and relevant proposition but added just one word in the proposition that rendered it inaccurate. Following the directions in the rubric raters penalized the student -0.5 points. The raters felt that such a penalty was overly harsh when the student otherwise gave evidence of being knowledgeable about the subject. In several instances raters made accommodations for such cases no doubt impacting the consistency of their ratings.

One final factor impacting the reliability of the ratings should be considered. While the rubrics were designed to account for important rating elements, they presented some problems for the raters. A review of the C-mapping task rubrics in Appendices B through E depicts rubrics designed to direct rater attention to proposition choice and the other rating elements. However, as raters focused their attention on each proposition they were required to consider all four rating elements simultaneously. It also became apparent towards the end of the study that the rubric did not account explicitly for all four rating elements at every level. The taxing cognitive load placed on the raters was possibly overcome by rater familiarity with the intent of the rubric, the course content, and student ability levels. Such rater preparation is not always plausible to attain in many educational settings and hence a rubric should be designed that accounts more clearly for the four rating elements.

Research Question 2

Because of the challenge with task 2 on first exam documented previously, conclusive evidence is not available to compare the reliability coefficients between these two scoring methods. However, some issues became evident as the study unfolded. First, the reliability coefficients for both concept-mapping tasks were relatively high for both relative and absolute decisions. As stated before, this was probably a function of the fact that the teaching assistants were very familiar with what material was and was not covered in class lectures and lab sessions. Second, the author assumed that the first scoring scheme where students were more constrained in their responses would have higher reliability ratings. This was the case with exam 2, but not with exam 1.

Regardless of these confounds the generalizability coefficients ranged form .72 to .92 which are considered moderately to very high.

Research Question 3

The D-study results provided projected generalizability coefficients for rating designs that would be more cost-effective to implement than the fully-crossed design used in this study. Under similar rating and instructional conditions the increase of one rater to two raters rating each map on one occasion provided the largest increase in the generalizability coefficient.

Research Question 4

The most feasible design to be used under similar study conditions would be the person-by-rater nested within occasion design. This design has one rater rate each map on one occasion and another rater rate each map on a separate occasion. These designs could feasibly be used by classroom teachers without an appreciable decrease in the overall generalizability coefficient.

Research Question 5

In summary the Pearson correlation coefficients were moderately high. They were higher than some studies such as Novak and Gowin (1984) who compared concept-map ratings with multiple choice scores, but not as high as others such as Anderson and Huang (1989) who compared concept-map ratings to standardized exams. In the case of study reported by Novak and Gowin, the lower correlations were attributed to the possibility that concept-mapping scores and other test items draw upon different cognitive processes. The lack of correlation in this study was primarily due to two factors in particular: (a) student lack of familiarity with scoring elements described in both C-mapping task rubrics, and (b) differences in the constraints imposed on the students between concept-mapping and criterion measure tasks.

Understanding of the Scoring Elements

Students in this study were familiar with the basic conventions of constructing a concept map. For example, few students constructed snake-like propositions that weaved through more than two concepts on the map. Few students failed to put arrows showing the direction of the propositions. Likewise, few students constructed maps without linking phrases. Where students lacked awareness was with regards to the scoring elements of the rubrics used with both tasks. As stated earlier, student propositions were scored based on proposition importance, accuracy, completeness, and conciseness. It appears that rater training on how to account for these scoring elements during homework assignments was not as uniformly clear as it should have been. Consequently, students were not held as accountable for these proposition rating properties so as to assist them in developing a working understanding of how to account for them when constructing a proposition. Hence, students with a solid understanding of how each set of concepts were interrelated may not have developed working knowledge of how to express that understanding.

Student motivation became another factor that may have impacted their investment in becoming familiar with the demands of the rating rubric. It appears that the overall weighting of concept-mapping scores relative to the entire point total of the class was not large enough to motivate students to take the time to meet with their assigned teaching assistant to receive feedback on their maps. The impact of this factor was that as the semester wore on fewer and fewer students visited with their assigned teaching assistant to review the details of their maps.

Different Task Constraints

It is important to note that a correlation between two measures is a function of the degree to which the criterion and target assessment tasks tap into the same traits or cognitive processes. As stated earlier several researchers hypothesized that concept maps target different cognitive processes than other more traditional test items. In this study this factor may have contributed to the concept map, essay, and interview scores not being as highly correlated. Hence, the lack of correlation may have been attributed to the following factors: (a) the different constraints imposed on student responses between concept-mapping and criterion measure conventions and (b) the different constraints imposed on students that were not caused by the differences in assessment conventions.

Constraints Impacted by Assessment Conventions

The main difference in assessment constraints between concept-map and criterion measures is manifest in the different ways in which propositions are expressed across these measures. When constructing a proposition on a concept map, the first concept is expressed at the beginning of the proposition and the second concept is expressed at the end. Instances exist where this constraint makes it difficult to link two concepts that otherwise would not be difficult to link in an essay or interview format. Essays and interview responses are expressed in a narrative format where as concept-map responses are not.

As raters search for propositions, many relationships eventually become apparent as students continue to write or verbally explain how everything fits together. For example, the relationship between the concepts *ATP* and *energy* could be expressed in an essay as follows: *When the terminal phosphate on an ATP molecule is broken, energy is released. This energy takes a form that can be processed by the cell. Expressing this same relationship in a concept-map proposition was challenging for many students.* During Dr. Booth's lectures students repeated the phrase, *ATP is the energy currency of the cell.* ATP and energy were among the list of concepts on the mapping task; however *cell* was not. This created a challenge for the students because while they could construct the proposition *ATP is the energy currency of the cell* they were at a loss as to how to express the same idea between ATP and energy, which could be, *energy that is usable by the cell is called ATP*.

In summary, the C-mapping task with the unique scoring elements described in the rubric did not afford students freedom of narrative. Students had to think carefully about all aspects of each conceptual relationship and then summarize it in an accurate, complete, and concise way. Such differences in assessment constraints appear to have had an impact on rating correlations.

Constraints Not Impacted by Assessment Conventions

Some differences in constraints were not a function of varying assessment conventions, but were more an artifact of how the assessor designed the assessments. Both C-mapping tasks under investigation in this study directed students to construct concept maps from a list of twelve to fourteen concepts. Under these conditions students were tested on their ability to connect the most closely related concepts. No prompts were given with regards to which concepts were more closely related and which were not. The essays and interviews on the other hand directed students to describe the relationship between two to four concepts. The questions themselves served as prompts that these concepts were in some way closely related. The results were that students made connections in their essays and interviews that they did not make on their concept maps because they were not prompted to do so. This appeared to have an impact on the score correlation between concept-map and criterion measures.

Keeping these issues in mind, it appears that there was greater shared variance between interview and essay scores and concept-mapping scores with task 1 than task 2. This may have been caused by students taking greater care to construct propositions on the first task than the second because of the risk of losing points for inaccurate linking phrases. Several students during the interviews indicated that this was the case. Students tended to be more focused in their responses on the first task, taking greater care to connect the key conceptual pairs. The second task proved to have greater conceptual variability because students were free to add five additional concepts. Those concepts in many instances were not evident in the essay or interview responses. Although students were encouraged to add as many concepts as they could to their essay and interview responses, and several did, they in many instances were not the same additions found on their corresponding concept maps. More research needs to be conducted analyzing the link between the constraints of each task with the cognitive activities they evoke (Ruiz-Primo et al., 2001).

Study Contributions

Studies investigating the degree to which concept-map assessments generate reliable scores have been conducted over several decades. (Ruiz-Primo et al., 2001; Ruiz-Primo & Shavelson, 1996). This particular study investigated the reliability of scores generated from two modified C-mapping tasks. What makes the C-mapping task unique is that it has shown to provide the best evidence of rating reliability while appreciably diminishing the threat to overall construct validity (Ruiz-Primo et al.). While showing great promise with regards to these two psychometric properties, several rating challenges have been raised with regards to their use (Yin et al., 2005). These rating challenges have been manifest in the difficulty of accounting for proposition choice when using the C-mapping task. The rubrics used in both C-mapping tasks in this study were designed to account for proposition choice along with proposition completeness, accuracy, and conciseness. Both evidenced score reliability, and to some degree (barring several confounds), criterion-related validity.

Future Research

Several issues emerged from the two studies conducted as part of the present research that inform the recommendations for future research offered in this section. First, recommendations are offered with regards to preparing an appropriate methodology for those interested in conducting similar studies and second, a recommendation is offered for researching the psychometric properties of a more robust scoring rubric.

An Appropriate Methodology

Three recommendations are offered for those researchers interested in developing an appropriate study methodology when conducting concept-map assessment research similar to this study. First, it is critical to choose those concepts from the content domain that will showcase student ability to produce strong conceptual interrelationships on their concept maps. Second, it is just as critical to assist students in understanding, practicing, and receiving feedback on their concept maps with those scoring elements that require students to draw upon targeted cognitive processes. Third, when correlating scores with a criterion measure, both measures should share as similar task demands, task constraints, and scoring methods as possible.

Content Domain

Subject matter content domains vary in the degree to which they can be mapped. Domains that contain concepts with definable boundaries (Donald, 2002) tend to lend themselves to being mapped more than those with less-definable concepts or boundaries. Those domains with ambiguously defined or *fuzzy* concepts (Merrill & Tennyson, 1977) tend to be less *mappable.* Nevertheless, even domains with fuzzy concepts could be mapped if students are provided with working definitions of those concepts based on specific contexts. For example, certain concepts found in medieval literature can be defined within the context of the piece of literature being studied. In such a scenario, quality propositions within such domains could be established based on their degree of importance, accuracy, completeness, and relevance as depicted within the given context. The important point to remember is that students must have access to the conceptual definitions as well as their conceptual interrelationships in order for concept mapping to be integrated within a course curriculum.

Instructors interested in using concept maps as viable instruction and/or evaluative tools should invest resources to ensure that their subject domain is clearly mappable for themselves and also for their students. Instructors who have tacked on concept-mapping to their curriculum without serious forethought as to the mappability of their subject have generally been disappointed with the results (Kinchin, 2000). As a learning, instructional, or evaluative tool, concept mapping can be viable only to the degree that an educator makes important front-end preparations. The following recommendations should be considered before adding concept mapping to any course curriculum. It is, therefore, critical that:

1. Each key concept as well as the conceptual interrelationships in the content domain is clearly defined.
2. The instructor has a command of the conceptual language of the course.
3. Students have access to resources where conceptual interrelationships are either laid out clearly or can be deduced.
4. The instructor must clearly establish that one of the learning outcomes of their course can be captured by concept maps. If this is not the case then concept mapping should not be considered.
5. Assessments targeting the cognitive process of interest must be clearly devised.
6. Resources providing specific and meaningful concept-mapping feedback must be in place.

Familiarity with the Scoring Elements

Once the scoring elements targeting the cognitive process of interest by the assessment have been developed, it is important to deploy resources that will provide students with meaningful training, practice, and feedback on their concept maps. The formative feedback should assist the students in becoming familiar with the scoring elements. If those scoring elements target those cognitive processes of greatest interest to both student and instructor, the formative aspect of their concept-mapping experiences should provide them with experiences that promote mastery of those cognitive processes.

Criterion Measures

The criterion measures should share, to the extent possible, similar task and scoring properties with the target measures with which they are being compared. Of course, no criterion measure will be identical to a measure under investigation. If this were the case, then one of the measures would be irrelevant. That said, it is important to design the criterion measure task and its corresponding scoring method in such a way to ensure a link between the concept-map and criterion ratings and the cognitive processes they are designed to evoke. In other words, while maintaining their distinctness in terms of being separate assessments both must tap into some shared aspects of the target construct or cognitive process.

Robust Rubric

It is the opinion of the author that follow-up studies should be considered that investigate ways in which the scoring elements used in this study could be made more accessible to raters, students, and instructors. If these scoring elements do reflect some important aspect of organized understanding such studies would indeed prove valuable to those practitioners interested in adding concept-maps to their assessment repertoire.

One recommendation in particular is that each proposition on a map be rated separately using a scale for each rating element. Four distinct scales could be developed measuring importance, accuracy, completeness, and relevance for each proposition on the map. A scoring method developed in this vein, would make the rating process less cognitively taxing for raters and yet assist them in accounting for all four rating elements.

Summary

Concept maps as learning and instructional tools have gained great traction over the last three decades (Liu, 2002; Mintzes et al., 1998) in promoting student-organized understanding. Concept-map assessments have not gained the same traction because of the complexity of scoring the idiosyncrasies of students' maps. This study represents a small effort to overcome some of the complexity associated with rating concept maps. Studies related to the development of robust concept-map scoring rubrics represent fertile ground for research that has yet to be carefully harvested. Such contributions could move forward a promising research agenda providing evidence of the degree to which concept-map assessments can be used as viable and defensible assessment tools for educators and researchers alike.

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APPENDIX A

Informed Consent

Consent to be a Research Subject

Introduction
Richard R. Sudweeks, Ph.D. and Ken Plummer M.Ed. are conducting a study, in an effort to analyze the effectiveness of concept maps as a measure of how students interconnect or interrelate concepts. You were selected to participate because you are currently taking Biology 100 with Dr. Booth.

Procedures
You have been randomly selected to participate in a ten to fifteen minute interview. In this interview you will be asked a series of questions regarding your understanding of how a list of concepts from the last midterm exam are interrelated. <u>This exercise will not be graded.</u>

Furthermore, after you have received a grade for your concept mapping and essay exam questions by Dr. Booth's TAs, your responses to these test questions will be rescored using a specialized scoring method. <u>The rescoring of your exams will in no way whatsoever affect your grade</u>.

Minimal Risks/Discomforts
Your interview will be audio taped and transcribed. The audio tapes will be kept in a locked filing cabinet and destroyed at the conclusion of the study. The transcripts will remain solely in the possession of the researchers (Dr. Richard Sudweeks and Ken Plummer) stored in a locked filing cabinet as well. The transcripts will not contain any information that would divulge your identity as an interviewee.

Benefits
There are no foreseeable benefits to students that would result from the interviews.

Confidentiality
All information provided will remain confidential and will only be reported as group data with no identifying information and only those directly involved with the research will have access to them. The resulting scores will be seen only by the researchers specified above and one of Dr. Booth's research assistants, Julie Low. Your concept maps, essays, and interview transcripts will be assigned a number, in an effort to maintain your anonymity. As previously explained, audio tapes will be destroyed and only the researchers will have access to the transcripts which will have no identifying information.

Compensation
If you consent to participate in the interview described above, as compensation for your time, you will be given a $10.00 gift certificate to be used at the BYU bookstore for each interview in which you participate.

Participation
Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade or standing with the university.

Questions about the Research
If you have questions regarding this study, you may contact Dr. Gary Booth at 422-2458, gary_booth@byu.edu; Dr. Richard R. Sudweeks at 422-7078, richard_sudweeks@byu.edu; Julie Low at 375-5703, julie.low@gmail.com or Ken Plummer at 422-4975, plummerkj@ldschurch.org.

Questions about your Rights as Research Participants
If you have questions you do not feel comfortable asking the researcher, you may contact Dr. Renea Beckstrand, IRB Chair, 422-3873, 422 SWKT, renea_beckstrand@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will and volition to participate in this study.

Signature:____ Date:______

APPENDIX B

Exam 1 Concept Map Task 1

Instructions: Construct a concept map showing how the concepts in the list below are interrelated. You are required to use every concept in the list below. Do not add additional concepts.

Activation Energy
Active Site
Anabolic Process
ATP
Catabolic Process
Cell
Competitive Inhibitors
Energy
Enzymes
First Law of Thermodynamics
Metabolism
Molecules
Noncompetitive Inhibitors
Second Law of Thermodynamics

Remember make as many connections as you like, but be sure that each linking phrase is as accurate as possible to avoid being penalized for an incorrect linking phrase.

Each linking phrase will be scored individually using the following accuracy scale:

Quality of Proposition	Descriptions and Examples
Accurate and Complete (2 points)	Communicates accurately the essential relationship between two closely related concepts without adding extra information.
Accurate but Incomplete (1 point)	Communicates accurate information between two closely related concepts but is missing some essential information.
Accurate but weak connection (0 point)	Communicates accurate information between two concepts that are not closely related.
Don't Care or Inaccurate (-.5 points)	Does not communicate an understanding of the relationship between the two concepts or information is inaccurate.

APPENDIX C

Exam 2 C-mapping Task 1

Instructions: Construct a concept map showing how the concepts in the list below are interrelated. You are required to use every concept in the list below. Do not add additional concepts.

Amino Acids
Anti-codon
Central Dogma
Codon
DNA
Lysogenic Cycle
Lytic Cycle
mRNA
Proteins
Replication
Ribosomes
Semi-conservatively
Transcription
Translation
tRNA
Viruses

Remember to make as many key connections as you can, but be sure that each linking phrase is as accurate as possible to avoid receiving negative points for an incorrect linking phrase.

Quality of Proposition	Descriptions and Examples
Accurate and Essential (2 points)	(1) Communicates accurately the essential relationship between two concepts as described in the syllabus, class lecture, or lab. (2) Information is essential to an understanding of the main theme of the map.
Accurate but Incomplete (1 points)	Communicates accurate information between closely related concepts, but is missing some essential information.
Accurate but not Essential (0 points)	(1) Makes accurate connections that are not essential to the main theme of the map, (2) Does not communicate an understanding of the relationship between the two concepts, (3) information is unnecessarily redundant.
Inaccurate (-.5 points)	Information is inaccurate

APPENDIX D

Exam 1 C-mapping Task 2

Instructions: Construct a concept map showing how concepts from the list below are interrelated. Remember, you must use each concept from the list below in your map. You may also <u>add</u> as many <u>other relevant concepts</u> as you would like that are not on the list.

ADP
ATP
Cellular Respiration
Cytoplasm
Energy
Glucose
Glycolysis
Inner Mitochondrial Membrane
Krebs Cycle
Mitochondria
Oxidative Phosphorylation
Pyruvates
Terminal Phosphate

Make as many connections as you would like. You will not receive negative points for an incorrect proposition. However you will receive more credit for concepts that are more closely related to one another.

Each linking phrase will be scored individually using the following accuracy scale:

Quality of Proposition	Descriptions and Examples
Accurate and Essential (2 points)	Communicates accurately the essential relationship between two closely related concepts without adding extra information.
Accurate but Incomplete (1 point)	Communicates accurate information between two closely related concepts but is missing some essential information.
Don't Care or Innacurate or Weak Association (0 points)	(1) Does not communicate an understanding of the relationship between the two concepts or (2) information is inaccurate or (3) concepts are not closely related.

APPENDIX E

Exam 2 C-mapping Task 2

Instructions: Construct a concept map showing how concepts from the list below are interrelated. Remember, you must use each concept from the list below in your map. You may add up to five other key concepts (not in the list below) that relate to the central theme of the map.

Antibodies
Cell-Mediated Immunity
Endotoxin
Exotoxin
Gram Negative Bacteria
Gram Positive Bacteria
Humoral
Immunity
Infection
Inflammation
Peptidoglycan
Viruses

Remember you will receive more credit for pairs of concepts that (1) are more closely related to one another and (2) relate to the central idea of what has been taught in the syllabus, class lectures, and lab sessions. You will not be given negative points for inaccurate connections.

Quality of Proposition	Descriptions and Examples
Accurate and Essential (2 points)	(1) Communicates accurately the essential relationship between two closely related concepts as described in the syllabus, class lecture, or lab. (2) Information is essential to an understanding of the main theme of the map.
Accurate but Incomplete (1 points)	Communicates accurate information between closely related concepts, but is missing some essential information.
Don’t Care or Inaccurate or Weak Association (0 points)	(1) Does not communicate an understanding of the relationship between the two concepts, (2) information is inaccurate, (3) Makes accurate connections that are not essential to the main theme of the map and (4) information is unnecessarily redundant.

APPENDIX F

Exam 1 Essay Task 1

Explain how the following concepts are interrelated:

activation energy
enzymes
competitive inhibition
non-competitive inhibition

APPENDIX G

Exam 2 Essay Task 1

Explain how the following concepts are interrelated:

ATP
ADP
Energy
Terminal Phosphate.

APPENDIX H

Exam 1 Essay Task 2

Describe the relationship between the following concepts:

Anti-codon
Protein
Transcription

Note. You will need to add other relevant concepts in your essay in order to make strong connections between the above concepts. You will be graded on your ability to make strong connections between the concepts, rather than just defining each concept.

APPENDIX I

Exam 2 Essay Task 2

Describe the relationship between the following concepts:

anti-bodies
exotoxins
macrophages

Note. You will need to add other relevant concepts in your essay in order to make strong connections between the above concepts. You will be graded on your ability to make strong connections between the concepts, rather than just defining each concept.

APPENDIX J

Exam 1 Interview

1. Explain the difference between an anabolic process and a catabolic process.
2. Explain the relationship between the following concepts:
    1. ATP
    2. Cell
    3. Energy
3. How would you explain the relationship between
    a. Active Site
    b. Competitive Inhibitors
    c. Enzymes
    d. Noncompetitive Inhibitors
4. Organize the following concepts hierarchically (from most general to least general) (Hint: some may be at the same level).
    a. Anabolic Process
    b. Catabolic Process
    c. Cell
    d. Enzymes
    e. Metabolism
5. Explain the relationship between
    a. Activation Energy
    b. Enzymes
6. How do the first Law of Thermodynamics and the Second Law of Thermodynamics impact the nature of energy?
7. Where, specifically, do Glycolysis, Krebs Cycle, and Oxidative Phosphorylation take place?
8. Explain the relationship between
    b. ADP
    c. ATP
    d. Terminal Phosphate
    e. Energy
9. How do Glycolysis, Kreb Cycle, and Oxidative Phosphorylation relate to one another?
10. How do they differ from one another?
11. What role does Pyruvate play in Cellular Respiration?
12. What role does Glucose play in Cellular Respiration?
13. What has your overall experience been with Concept Mapping this semester?
14. How fair and helpful has the grading of your concept maps been?

APPENDIX K

Exam 2 Interview

1. What is the connection between tRNA and a codon?
2. What role does mRNA play in the central dogma?
3. How are amino acids important to the process of translation?
4. How does replication effect the lysogenic cycle versus the lytic cycle?
5. What is the difference between cell-mediated and humoral immunity? Explain those differences in as many ways as you can.
6. Describe the difference between gram positive and gram negative bacteria. What causes these differences?
7. What role do anti-codons play in the production of proteins?
8. Describe the difference between active & passive immunity.
9. Why are there more macrophgages and anti-bodies at the site of inflammation?
10. Describe your overall experience with concept mapping this semester (both positive and/or negative).

APPENDIX L

Concept Mapping Instructional Packet

Instructional Unit
Designed to Prepare Students to Use Concept Maps as part of Course Instruction

By Ken Plummer
Brigham Young University

Contents

Purpose

The purpose of this instruction is to train students how to construct concept maps in preparation for class assignments.

How to Use this Guide

The guide goes through specific instructions regarding the purpose, uses, and components of a concept map. You are encouraged to take the time, effort, and possibly even patience required to learn how to construct a map in the practice exercises in preparation for using concept maps in this course. The training should take 40 to 60 minutes to complete.

Benefits

Students who have acquired conceptual knowledge know more than isolated bits and pieces of information. Their knowledge is organized into coherent frameworks [1] [2] They understand how related concepts are interconnected [3]. They are able to think with the concepts they have acquired and solve problems with understanding that they otherwise could not [4].

A concept map is a tool that will assist you in constructing and organizing visually the information you are learning. It is not meant to replace but enhance your study and learning strategies. By putting forth consistent effort, you will find it to be an invaluable aid, as you think more critically about how the information you are taught is meaningfully interconnected.

---

[1] Bransford, J.D., Brown, A.L. & Cocking, R.R. (Eds.) (2000). How people learn: Brain, mind, experience and school. Washington, DC: National Academy Press.

[2] Donald, J.G. (2002). Learning to think: Disciplinary perspectives. San Francisco: Jossey-Bass.

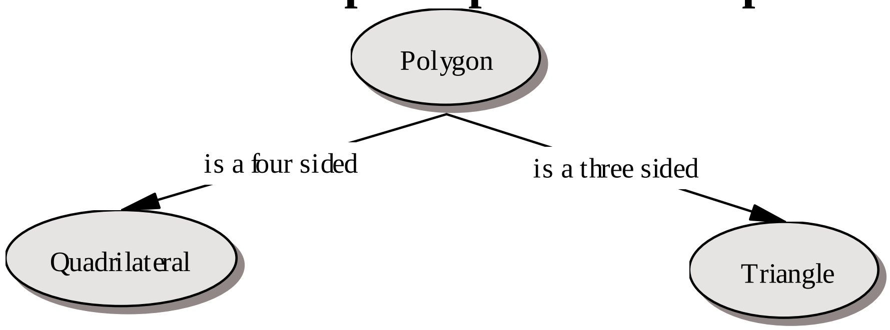
[3] Jonassen, D.H., Beissner K., & Yacci, Michael. (1993). Techniques for representing, conveying, and acquiring structural knowledge. Hilldale, NJ: Lawerance Erbaulm Associates.

[4] Herron, J.D. (1996). The chemistry classroom: Formulas for successful teaching. Washington, DC: American Chemical Society.

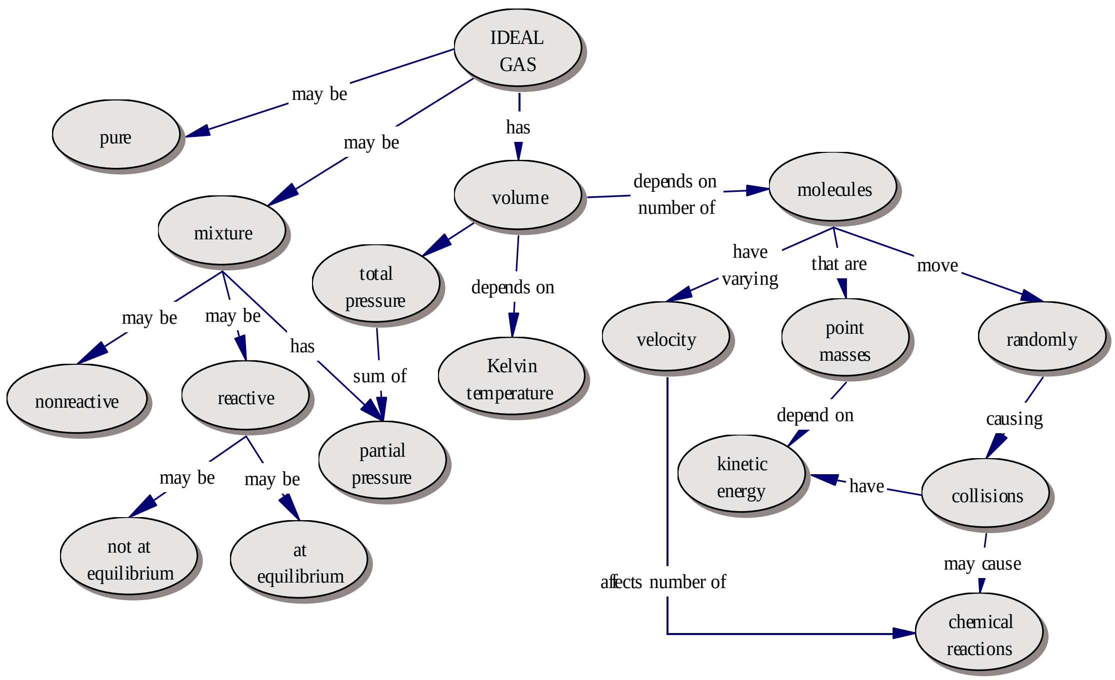
What is a Concept Map?

A ***concept map*** is a graphic representation intended to reveal your understanding of how concepts relate to one another.

Concept Maps can be simple



Or Complex [5]



[5] Herron, J.D. (1996). *The chemistry classroom: Formulas for successful teaching*. Washington, DC: American Chemical Society.

What are Concept Maps used for?

They are used to:

1. Help teachers organize their teaching. *(Instruction)*
2. Help teachers see how students organize the information they are taught. *(Evaluation)*
3. Help students connect the information they learn in a meaningful way *(Learning)*

What is a concept?

If you have a *concept* of something you have an idea or a mental model of what it is.

Look at this word: **Chair**

What comes to mind when you see this word? Do you see four legs, a back, a seat? The chair in your mind probably does not swivel or recline yet there are chairs that do just that.

The concept chair is defined by its properties. These properties must be shared by anything that can be called a "chair".

Here is the test: Do all chairs have _______________?
If the answer is yes then that property is an attribute of the concept called "chair".

Do all chairs have *four legs*? No, think of recliners.
Do all chairs have *a place to sit*? Yes

Therefore, all chairs do not share the attribute of having four legs, but they do share the common attribute of possessing a place to sit.
Concepts can be objects *(chair)* events *(earthquake)* processes *(photosynthesis)* conditions *(unemployed)* etc.

How are concepts *connected* to one another?

Concepts relate to other concepts in many different ways. Here are a **few examples** of the how they may relate:

Causal relationships

concept → Heat ***melts*** ice ← concept

Part-whole relationship

An apple ***is a kind of*** fruit

Functional relationship

Podiatrists ***fix*** feet

Utility relationship

Fire ***requires*** oxygen

Material relationship

Trees ***are made of*** wood

Illustrative relationship

The sun ***is an example of*** a star

Quantitative relationship

Flamingos ***have three*** *toes*

Qualitative relationship

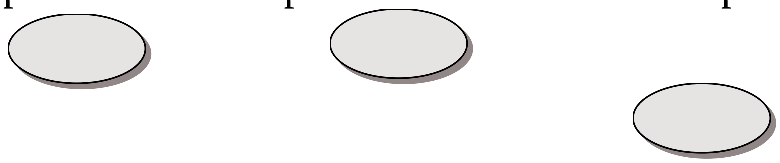
Ice ***is*** cold

Proximate relationship

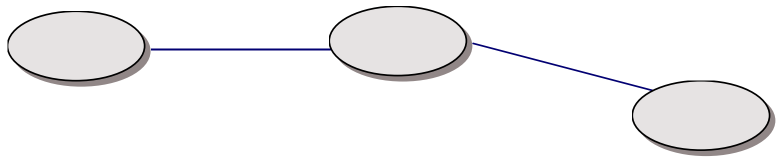
Island ***is surrounded by*** water

What are the *components* of a Concept Map?

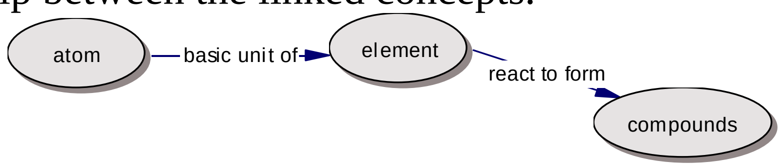
1. *Nodes* are ellipses that each represents a different concept.



2. *Links* are lines that connect various nodes.

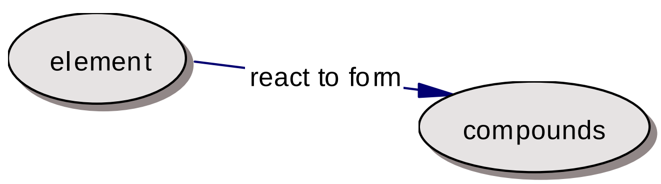


3. *Linking phrases* are the label for each line that briefly expresses the relationship between the linked concepts.



(Notice how the arrow shows the direction of the linking phrase)

4. The combination of any two nodes and the label that connects them is a *proposition*.



These propositions are the basic unit of meaning in a concept map and function as a *sentence*:

"Elements react to form compounds"

How do you *create* a Concept Map?

First – *Select the most general concept*

Study the list of concepts[6] below:

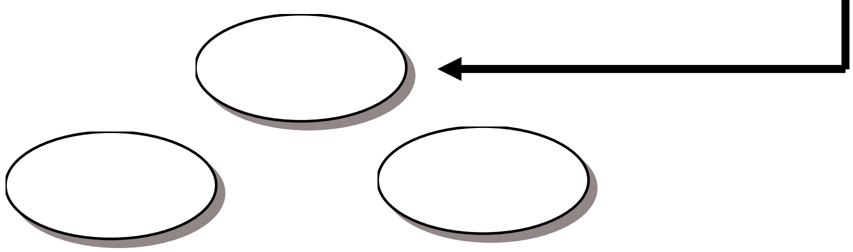
Animals
Cow
Dog
Grass
Living things
Plants

GOAL OF THIS SECTION: You will be able construct a simple concept map. **(pgs. 8-9)**:

Write down the *one* concept that is the most general and all encompassing in the ellipse below:

Second – *Select other closely related concepts*

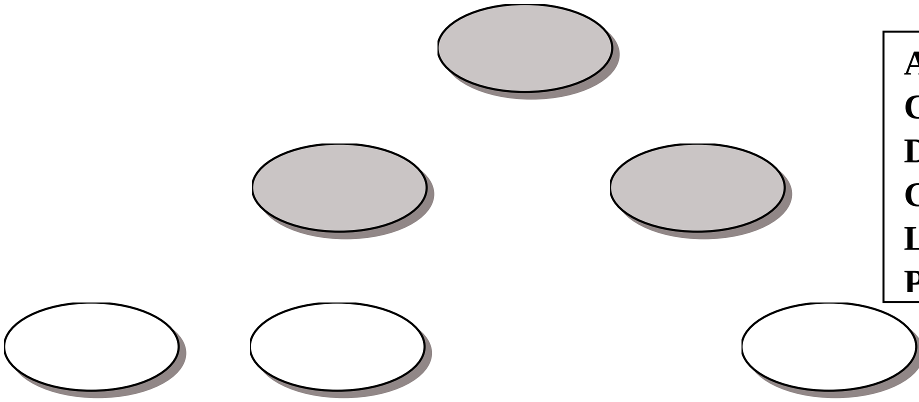
Now look at the remaining concepts and select those concepts that are most closely related to the main concept you selected.



[6] Gunstone R. & White R. (1992). Probing understanding. New York, NY: The Falmer Press.

Third – *Select other concepts*

Add the other concepts from the list provided. As you add each new concept, **draw lines** with **no arrows** (yet) connecting concepts that are related to one another.



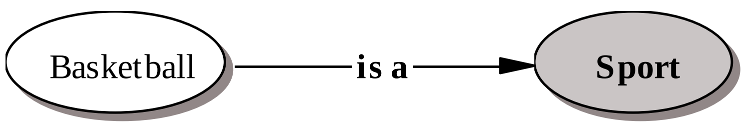
Animals
Cow
Dog
Grass
Living things
Plants

Fourth – *Label the linking lines*

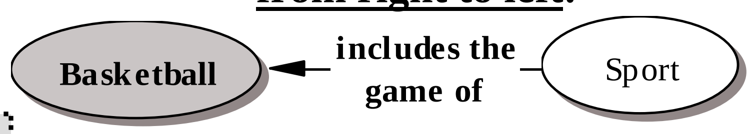
When labeling the lines, be sure to show the direction of the arrows (→) between each concept. **Remember:** Arrows can go from either

> *NOTE.* When two concepts are connected, they must make a complete **independent sentence.**

left to right:

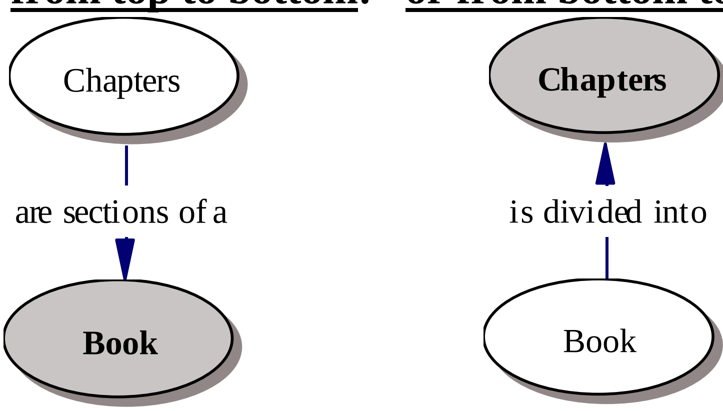


from right to left:



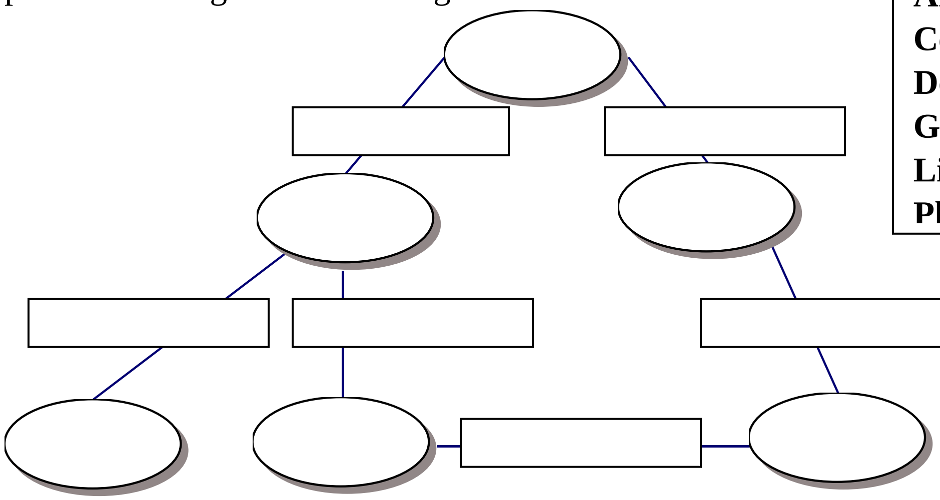
> ***NOTE.* Each pair of concepts and their linking phrase act as Complete Independent Sentences**

from top to bottom: **or from bottom to top:**



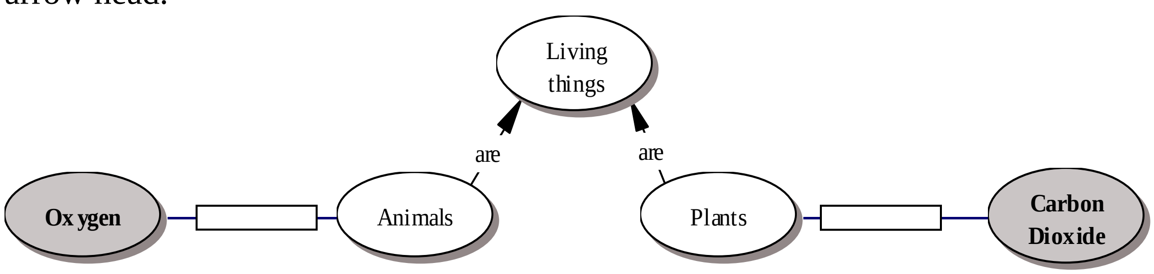
***NOTE.* THERE IS NO SET WAY TO STRUCTURE YOUR MAP.** Do your best to put the more general concepts above the more specific concepts. Where you need to focus most of your attention is on the **linking phrases**. It is here where your true connected understanding is demonstrated. Now, label each line with a word or phrase that describes how the connected concepts are **related**. Use precise wording without writing a whole sentence.

Animals
Cow
Dog
Grass
Living things
Plants



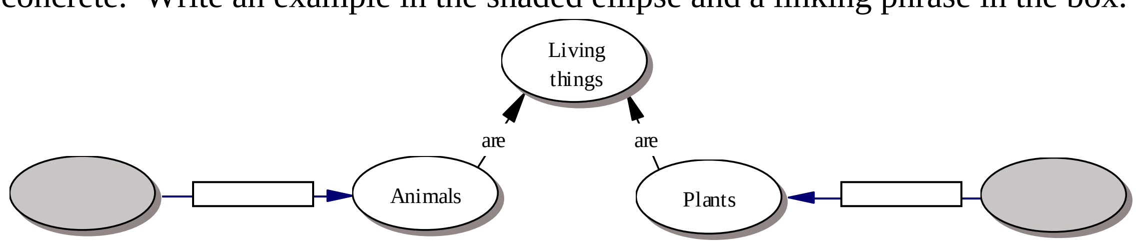
Fifth – *Select other concepts*

You may add other concepts that are not on the list. Fill in the appropriate linking word or phrase below. Remember to indicate the direction of the sentence with an arrow head.



Sixth – *Importance of Examples*

If a concept is abstract, an example can be a powerful tool to make it more concrete. Write an example in the shaded ellipse and a linking phrase in the box.



Frequently Asked Questions

What is the hardest part about creating a concept map?

1. Making the Links. The links in our example were fairly simple and straight forward. However, in many instances we don't realize how fuzzy our understanding really is regarding how concepts are interrelated until we have to actually express that relationship ourselves. Even though this requires hard work, this is also the aspect of concept mapping that stimulates real, meaningful learning.

2. Refining your Map. You will find that constructing a map is like writing an essay. You will refine it, restructure it, and in doing so the organization and the clarity of your connections will improve. When drawing a concept map on paper you will need to be prepared to do a lot of **<u>ERASING</u>!** The more you spend time on your map the more you will **<u>erase</u>**, the more you will **<u>learn</u>**.

Your map should have a Theme.

A map that indicates the various **<u>materials</u>** used to construct a rocket will look differently than a map that shows the **<u>processes</u>** involved in constructing a rocket. Every link is affected by the overall theme of the map.

How do I know if my concept map is correct?

The first cartographers made maps that look silly to us today. However, as they became more experienced and more information became available to them, the maps became better representations of what they were depicting and more useful, too. Such will be the case as you refine your concept mapping skills.

How much effort should I put into organizing the map structure?

No two maps will ever be the same. In some cases organization is critical. For example, *living things* would probably not be placed under *cows*. However, there could be a rationale for doing just that, depending on your own personal map making style. The **<u>linking phrase</u>** you make between two concepts is the most critical aspect of concept mapping.

If I am able to map it, does that mean I really understand it?

The map on the paper and the map in your mind may not be identical. As you use your map in several different settings *(e.g., taking class notes, studying the text, doing homework problems)* the map on paper will become a part of the map in your mind.

First Practice

> **GOAL OF THIS SECTION:** You will be able to construct your own concept map from a list of concepts using the guidelines provided **(pgs. 11-13)**

Read the passage below[7] and on a blank sheet of paper construct a concept map using the concepts listed below the passage *(see page 6-9 if you wish to review the general guidelines for concept mapping).*

The elephant has three living species: the Savannah Elephant and Forest Elephant (which were collectively known as the African Elephant) and the Asian Elephant (formerly known as the Indian Elephant). Asian elephants are smaller than their African relatives, and the easiest way to distinguish the two is the smaller ears of the Asian Elephant. Elephants are the largest living land mammals.

Based on what you just read, construct a concept map using the list of concepts below:

African Elephant
Asian Elephant
Elephant
Forest Elephant
Land Mammal
Savannah Elephant

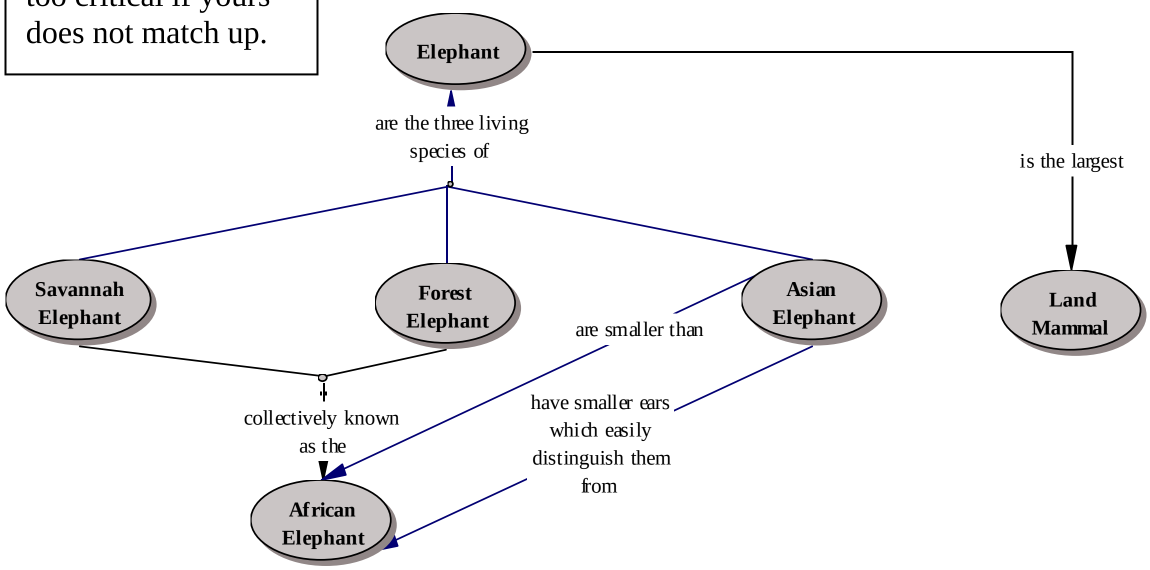
- As soon as you have finished go to the next page and look at one persons approach to mapping this passage

[7] Taken from Wikipedia: Elephants – http://en.wikipedia.org/wiki/Elephants

Elephant Passage Concept Map

Here is one attempt. Use this map only as a guide to consider one way this subject might be mapped.

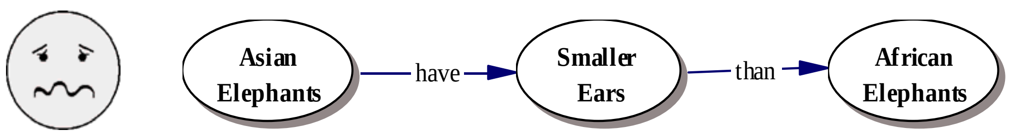
Note!!! The concept map below took five tries to get it to its final state (shown below). Use this as a guide but don't be too critical if yours does not match up.



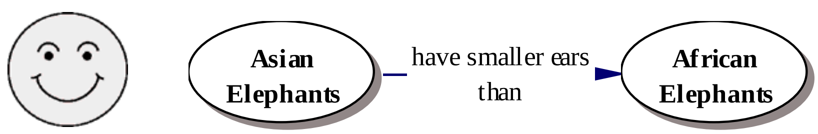
Points to Consider

1. **Linked concepts should read like a sentence.** Remember that **each pair of concepts** and its linking phrase must be able to stand on their own as an independent sentence.

Less Effective Example: (a sentence created out of **three** linked concepts)



Effective Example: (a sentence created out of **two** linked concepts)



2. **Don't try to do too much at once.** Here is another approach to consider: As you look at a list of concepts **rank them** from general to specific. *(Note. some concepts have about the same level of generality or specificity)*

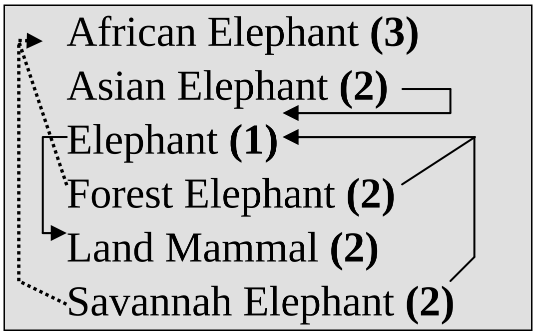
NOTE. **African Elephant** would make more sense as a **2** however since living species are divided into Asian, **Forest**, & **Savannah** in this article, we put it as a **descriptor** of the last two rather than a **category** over them.

African Elephant **(3)**
Asian Elephant **(2)**
Elephant **(1)**
Forest Elephant **(2)**
Land Mammal **(2)**
Savannah Elephant **(2)**

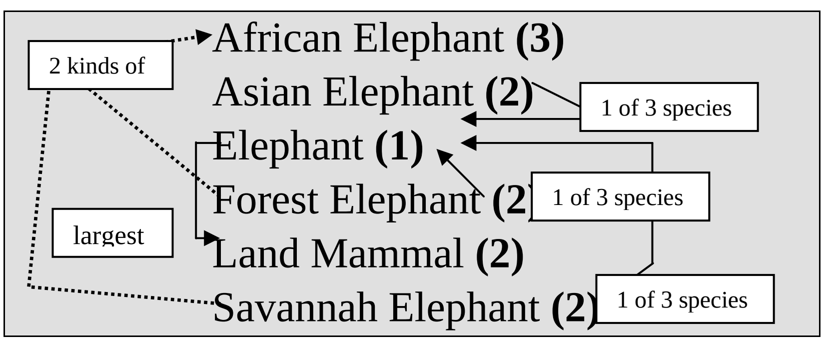
NOTE. We might be tempted to put land mammals as **1**. And outside of the article we would be correct. However the article does not say that an elephant is a land mammal but says it is the **largest** land mammal. In this case this concept is used to describe an attribute of the elephant, not tell us that it is a species under the land mammal

<Continued >

Draw lines to show connections



Write Abbreviated Links



Now you are ready to Map!

Second Practice

GOAL OF THIS SECTION: You will be able to construct a meaningful map with a more challenging subject **(pgs. 14-15)**

Read the passage below[8] and on a blank sheet of paper construct a concept map using the concepts listed below the passage.

Science refers to either: the scientific method – a process for evaluating empirical knowledge; or the organized body of knowledge gained by this process.

Empirical knowledge is knowledge obtained by experience. It differs from a priori knowledge (knowledge gained by reason) because it must be experienced first. Thus empirical knowledge is known as a posteriori knowledge or knowledge gained after the fact or after the experience."

Thus, mathematics and logic are considered a priori because you cannot experience them directly. On the other hand natural and social sciences are usually considered a posteriori because they seek knowledge through experience.

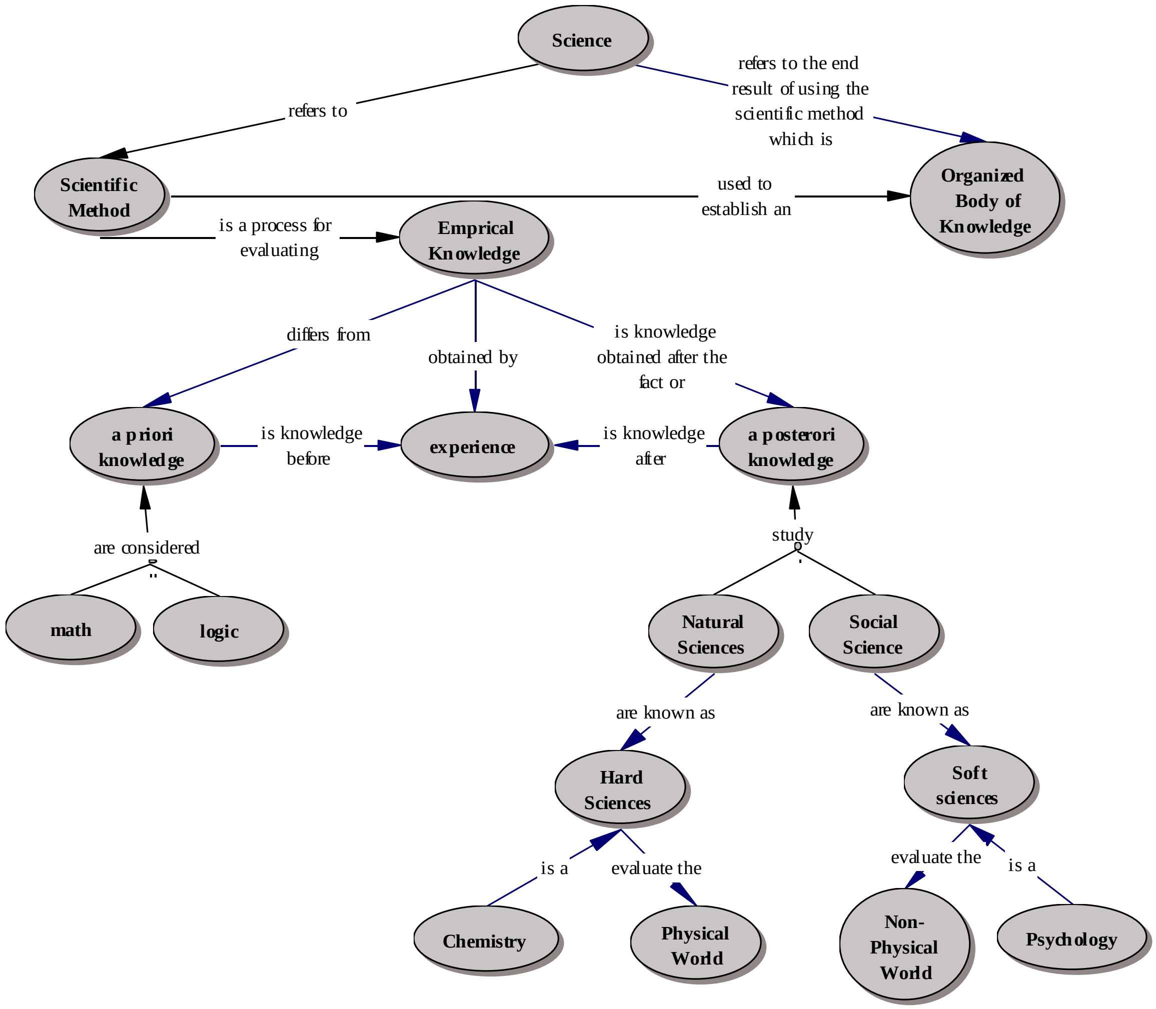
Natural sciences are called hard sciences (e.g., Chemistry) because they are used to evaluate experiences from the physical world. Social sciences (psychology) are termed soft sciences because they are used to evaluate experiences from the nonphysical world.

Based on what you just read, construct a concept map using the list of concepts below:

A posteriori knowledge	*Non-physical world*	*Soft sciences*
A priori knowledge	*Organized Body of Knowledge*	**Examples:**
Empirical knowledge	*Physical world*	*Chemistry*
Experience	*Science*	*Logic*
Hard sciences	*Scientific method*	*Math*
Natural sciences	*Social sciences*	*Psychology*

Science Passage Concept Map

[8] Taken from Wikipedia: Elephants – http://en.wikipedia.org/wiki/Elephants


Science
refers to
refers to the end result of using the scientific method which is
Scientific Method
used to establish an
Organized Body of Knowledge
is a process for evaluating
Emprical Knowledge
differs from
obtained by
is knowledge obtained after the fact or
a priori knowledge
is knowledge before
experience
is knowledge after
a posterori knowledge
are considered
study
math
logic
Natural Sciences
Social Science
are known as
are known as
Hard Sciences
Soft sciences
is a
evaluate the
evaluate the
is a
Chemistry
Physical World
Non-Physical World
Psychology

Demonstrating your Knowledge

GOAL OF THIS SECTION:
You will see how concept mapping can assist you in demonstrating your understanding **(pg. 16)**

Answering Test Questions

As you become adept constructing concept maps, you will find that your thinking becomes more organized and your reasoning becomes more thoughtful.

In turn, these skills will enable you to write better essays, produce better conceived research papers, and teach concepts to others more effectively.

As a way of demonstrating what you have learned:

1. Review the science concept map you constructed.
2. Study it carefully considering how everything is connected.
3. Close your eyes and try to verbally recreate the map in your mind.
4. When you have finished take a few minutes and answer the questions below.

Multiple Choice

Which university subject would use knowledge that is analyzed empirically?

a. Bio-chemistry
b. Advanced Logic
c. Calculus
d. Spanish Literature

True or False

Empirical knowledge encompasses any kind of knowledge regardless of its source. T F

Essay Question (short paragraph)

Describe the true nature of empirical knowledge and contrast it with other kinds of knowledge. *(use back side of this page)*

Class Assignment 1

Due by ___________

APPENDIX M

Biology 100 Concept Map Training

Biology 100 Concept Map Training

1. Purpose of Concept Mapping
2. How to concept map
3. Linking Phrase Training
4. Concept Map Practice
5. Calendar
6. Concept Map Assignments for Lecture 4 and 5

1. Purpose of Concept Mapping

In order to "really" understand a subject like biology, you need to know

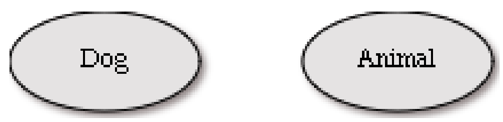
- Biological **Facts** – *Watson and Crick discovered the structure of DNA.*
- Biological **Concepts** – *DNA or mRNA*
- How biological **Concepts are Interrelated** – ***mRNA*** *is a mobile transcription of* ***DNA***

In Dr. Booth's class this Fall you will learn facts, concepts, and how these concepts interrelate with one another. We will use Concept Mapping as a way to see how the concepts you learn this semester are interrelated.

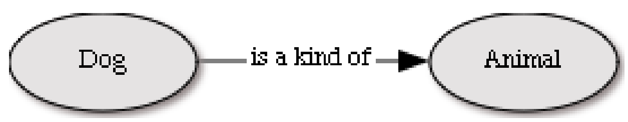
2. How to Concept Map

A concept map has –

- Concepts - that you write with a word in a circle



- Linked Concepts – which communicate a "complete thought". The arrow shows the direction of the thought.

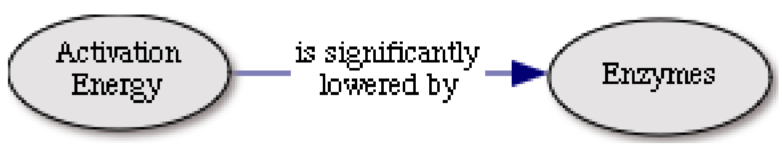


3. Linking Phrase Training

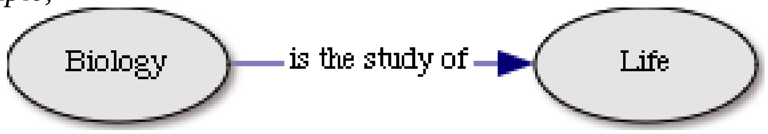
Kinds of linking phrases:

There are two kinds of linking phrases you will encounter in your future assignments

- *Link 1.* One that is true and informative (because you might not have known it before)
  For example,



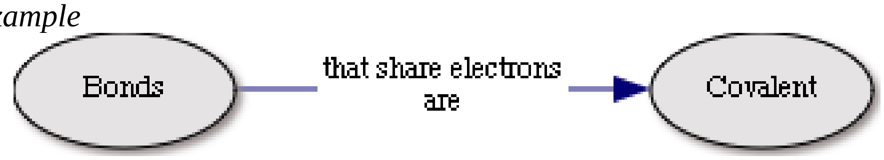
- *Link 2*. One that is true but not very informative (because you probably already knew it)
  For example,



Many of these obvious links tend to be those links that give the concept map its structure. For example, *organs* are made up of *tissues* which are made up of *cells* which are made up of *molecules*. Notice that this information is fairly obvious, but it does provide the organizational structure of the map, like an outline. After you have the organizational structure in place *(link 2)*, then you may add concepts that create more informative linking phrases *(link 1)*.

What makes a helpful linking phrase:
The linking phrase should communicate the *essential relationship* between two concepts with *as few of words as possible*. For this to happen, you usually will not add any new concepts in the linking phrase, unless absolutely necessary. Read the following examples:

Good example

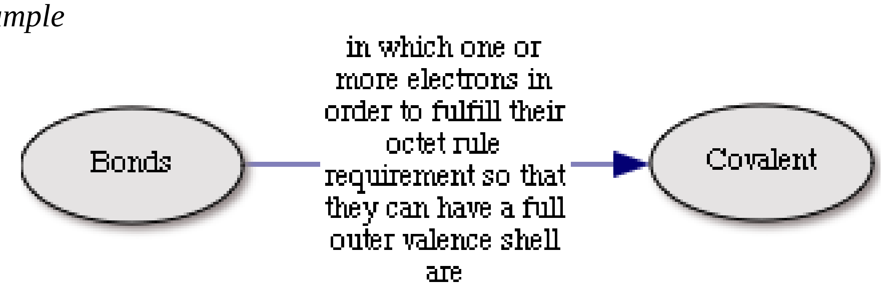


Notice that the concept "electrons" is in the linking phrase, because it is a critical part of the relationship between the concepts "bonds" and "covalent".

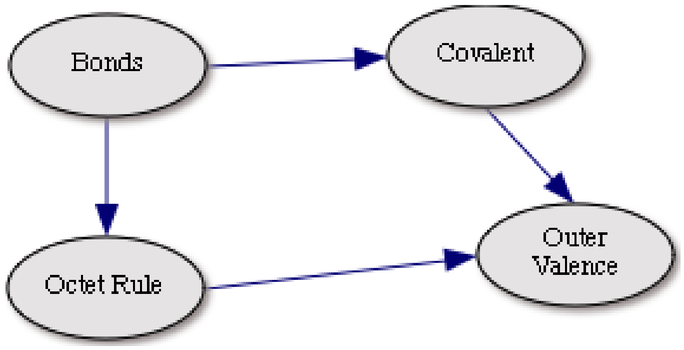
Bad example

This link may be true, but it could be a bit more informative.

Bad example



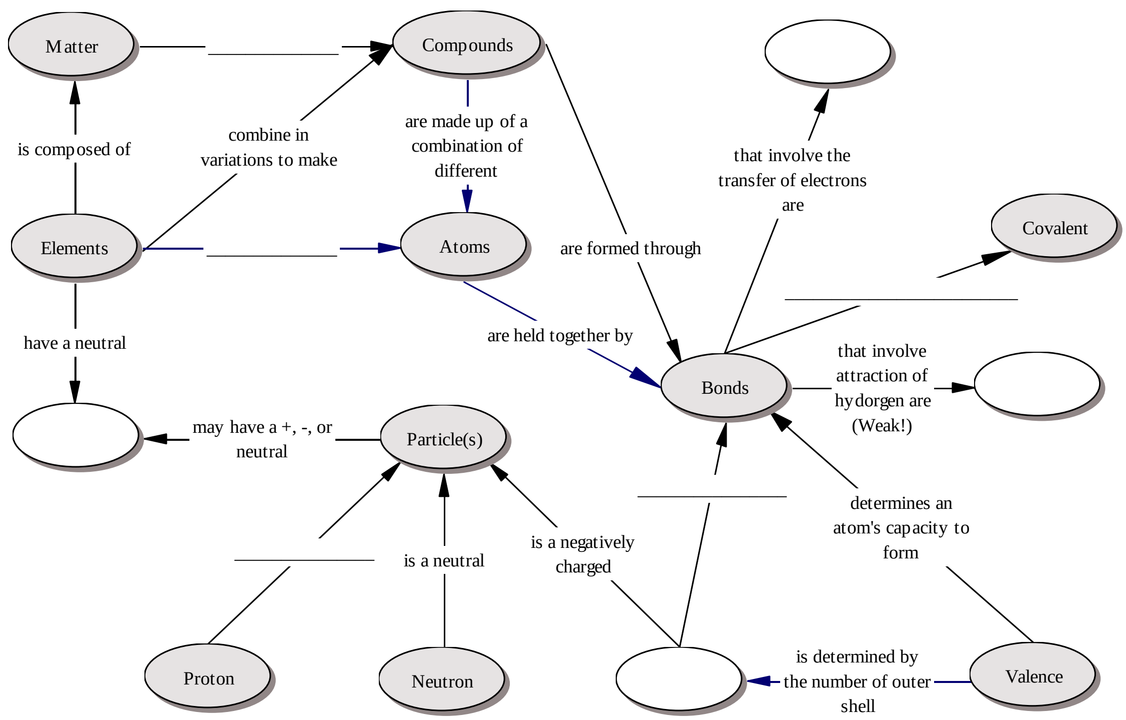
This linking phrase could be shorter and still communicate the essence of the relationship between the two concepts. It might be better to break this link apart and make connections between concepts like “octet rule”, “outer valence”, “bonds”, and “covalent” in a larger concept map as shown below:



4. Concept Map Practice Exercise

Read the following paragraph and then fill in the blanks below. Note that a concept (circles below) or linking phrase (lines below) may be blank.

All matter is composed of compounds. Compounds are made up of a combination of different atoms, held together by bonds. Bonds come in a variety of forms, depending on how the electrons of the atoms interact. In an ionic bond, the electrons from one atom are transferred to another atom. In a covalent bond, the electrons are shared. In hydrogen bonding, weak bonds are formed through the attraction of hydrogen atoms. The number of electrons that are available to form bonds are found in the valence shell of the atom. The valence is determined by the number of electrons in the outer shell. Electrons (negatively charged), protons (positively charged), and neutrons (no charge) are all particles contained in an atom. An element is composed of identical atoms.


Matter
Compounds
is composed of
combine in variations to make
are made up of a combination of different
Elements
Atoms
are formed through
that involve the transfer of electrons are
Covalent
have a neutral
are held together by
Bonds
that involve attraction of hydorgen are (Weak!)
may have a +, -, or neutral
Particle(s)
is a neutral
is a negatively charged
determines an atom's capacity to form
Proton
Neutron
is determined by the number of outer shell
Valence

5. Calendar for the next four weeks

		September 4-7		
Mon.	Tues.	Wed.	Thurs.	Fri.
		Class Lecture 1		Class Lecture 2
			New Concept Map Lecture 4-5 Assigned	
		September 11-15		
Mon.	Tues.	Wed.	Thurs.	Fri.
Class Lecture 3		Class Lecture 4		Class Lecture 5
		September 18-25		
Mon.	Tues.	Wed.	Thurs.	Fri.
New Concept Map Lecture 6-7 Assigned				
Students Turn in Lecture 4-5				
Class Lecture 6		Class Lecture 7		Class Lecture 7
TAs Grade Concept Map Lectures 3-5				
			TAs return Concept Map Lectures 4-5	
			Students meet with TAs during office hours to correct concept map lectures 4-5 & receive full credit	
		September 28- October 2		
Mon.	Tues.	Wed.	Thurs.	Fri.
New Concept Map Lecture 8-9 Assigned				
Students Turn in Lecture 6-7				
Class Lecture 8		Class Lecture 9		Class Lecture 9
TAs Grade Concept Map Lectures 6-7				
			TAs return Concept Map Lectures 6-7	
			Students meet with TAs during office hours to correct concept map lectures 6-7 & receive full credit	

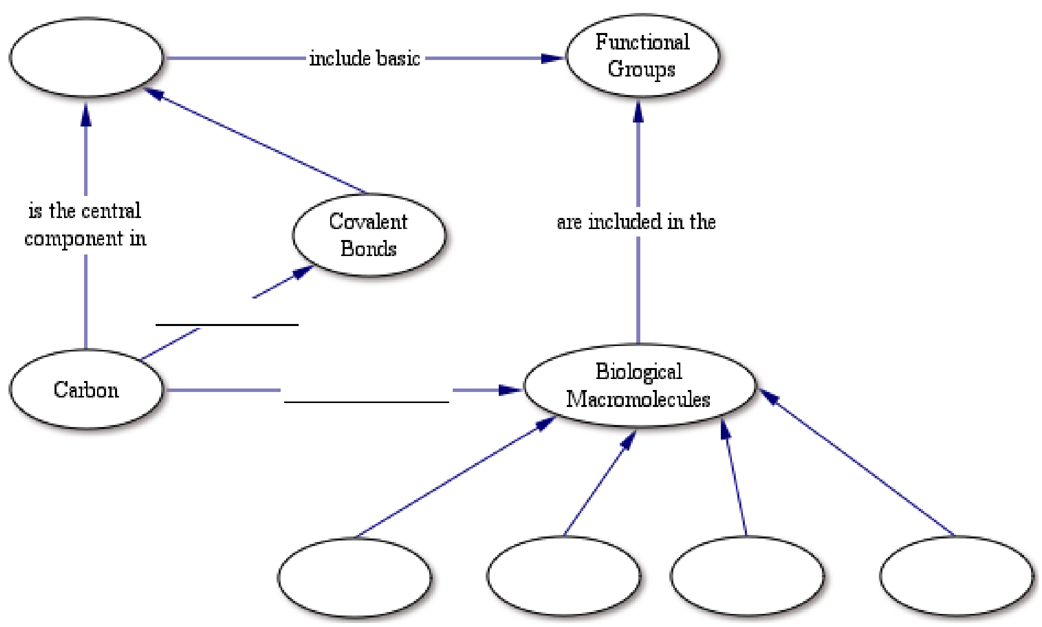
Points to remember:

- At the beginning of the third week, all concept mapping assignments must be turned in on Monday **<u>before class starts</u>** to your TA.
- Also at the beginning of the third week, the next set of concept mapping assignments will be given out on Monday **<u>before class starts</u>** by your TA.
- All concept mapping assignments will be returned to you graded on Thursday at the beginning of your lab session.
- If you wrote incorrect or less than ideal linking phrases, you can visit with your TA during their office hours to receive feedback on the incorrect links. By doing so, you will be **<u>given full credit</u>** for any points you missed. *Note. This option is only available to those students who the TA believes gave a diligent effort to finish the concept mapping assignment. If, in the TA's opinion, a student did not give such an effort, the opportunity to meet with the TA and correct the map for full credit, will not be offered.*

6. Lecture 4 Concept Mapping Assignment

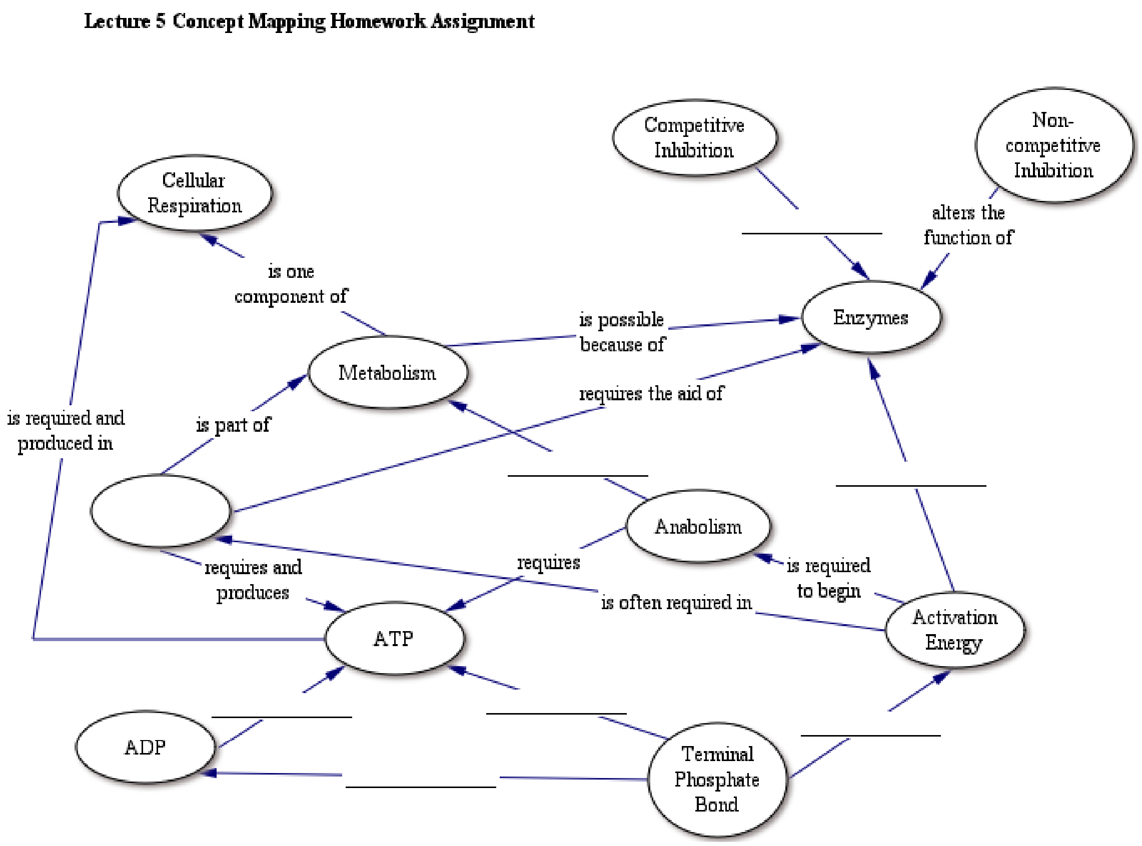
Read lecture 4 in the class syllabus and listen carefully as Dr. Booth presents lecture 4 material in class. Then fill in the blanks below. You may add other meaningful concepts and linking phrases to the map if you would like.

Lecture 4 Concept Mapping Homework Assignment

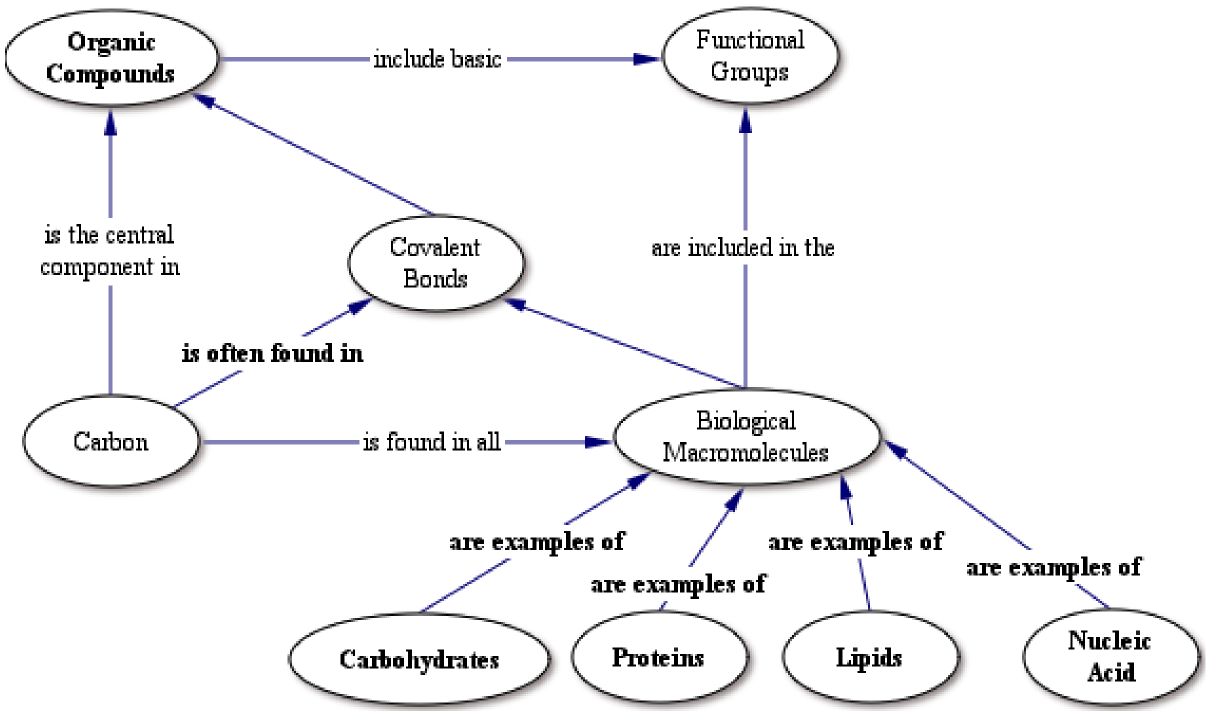


Lecture 5 Concept Mapping Assignment

Read lecture 5 in the class syllabus and listen carefully as Dr. Booth presents lecture 5 material in class. Then fill in the blanks below. You may add other meaningful concepts and linking phrases to the map if you would like.



Lecture 4 Concept Mapping Homework Assignment Master Map



Lecture 5 Concept Mapping Homework Assignment Master Map