DOCUMENT RESUME

ED 347 055 SE 052 035

AUTHOR Schreiber, Deborah A.; Abegg, Gerald L.

TITLE Scoring Student-Generated Concept Maps in Introductory College Chemistry.

PUB DATE 91

NOTE 25p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Lake Geneva, WI, April 7-10, 1991).

PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.

DESCRIPTORS Chemistry; *Cognitive Development; Cognitive Structures; *College Science; *Concept Formation; Evaluation; Higher Education; *Misconceptions; Science Education; Thinking Skills

IDENTIFIERS *Concept Mapping

ABSTRACT

This study presents a quantitative method for scoring concept maps generated by students learning introductory college chemistry. Concept maps measure the amount of chemical information the student possesses, reasoning ability in chemistry, and specific misconceptions about introductory and physical chemistry concepts. They provide a visualization of cognitive structure. When a student draws a concept map for chemical reactions, the result is a model of the student's conceptual framework for understanding the concepts and propositions of chemical change. Developing a valid method for scoring student concept maps will enable educators to evaluate student knowledge free of the bias and arbitrariness often associated with qualitative reviews. Concept maps may be evaluated quantitatively by categories. The category score for propositional validity reflects student reasoning ability in chemistry. The score significantly correlates with formal reasoning ability in chemistry. The category score for hierarchical structure reflects the amount of chemical information possessed by a student. Students who possess large amounts of information about chemistry, position more vocabulary words within each hierarchical level than the student who demonstrates limited chemical knowledge. It is suggested that the greater a student's understanding of introductory chemistry concepts the more strands are employed in mapping concepts and propositions related to chemical reactions. Low strand count reflected specific misconceptions about Avogadro's Number, the mole concept, and the Law of Conservation of Matter. (Author/MM)

Scoring Student-Generated Concept Maps in Introductory College Chemistry

Scoring Student-Generated Concept Maps in Introductory College Chemistry

Paper Prepared for
The National Association For Research in Science Teaching
1991 Annual Meeting

Deborah A. Schreiber, Ed.D.
Chemistry Education
Wentworth Institute of Technology
Boston, MA 02115

Gerald L. Abegg, Ph.D.
Science Education
Boston University
605 Commonwealth Avenue
Boston, MA 02215

Scoring Student-Generated Concept Maps in Introductory College Chemistry

ABSTRACT

This study presents a quantitative method for scoring concept maps generated by students learning introductory college chemistry. Concept maps provide a visualization of cognitive structure. When a student draws a concept map for chemical reactions the result is a personification of the student's conceptual framework for understanding the concepts and propositions of chemical change. Developing a valid method for scoring student concept maps will enable educators to evaluate student knowledge free of the bias and arbitrariness often associated with qualitative reviews.

The scoring methodology presented in this study permits evaluation of the learning characteristics of students in chemistry. The concept map measures the amount of chemical information the student possesses, reasoning ability in chemistry, and specific misconceptions about introductory and physical chemistry concepts.

This research has demonstrated that concept maps may be evaluated quantitatively by categories. The category score for propositional validity reflects student reasoning ability in chemistry. Propositional validity is measured by the ratio of valid connecting lines to total number of connecting lines drawn (per strand). This score significantly correlated with formal reasoning ability in chemistry.

A second category score was identified for hierarchical structure. The category score for hierarchical structure reflects the amount of chemical information possessed by a student. Students who possess large amounts of information about chemistry position more vocabulary words within each hierarchical level th: . the student who demonstrates limited chemical knowledge.

The data in this research also suggest the greater a student's understanding of introductory chemistry concepts the more strands s/he employs in mapping concepts and propositions related to chemical reactions. Low strand count reflected specific misconceptions about Avogadro's Number, the mole concept, and the Law of Conservation of Matter.

This study documents a method for objectively measuring student heuristic processing in chemistry. Educators previously have used the concept map as an instructional tool and as a *metalearning* strategy. Successful quantitative evaluation of the concept map enables it to be used as a diagnostic tool to monitor and explore conceptual change.

One application of this study's findings is the utilization of concept map category scores to make informed decisions about instructional design. This will enhance rather than hinder student reconceptualization. Educators in science may consult student concept map category scores to gain information about student understanding in a given domain. Effective educational programs which strive to remediate misconceptions about scientific knowledge may use this information to develop instructional strategies complementary to individual student learning traits. Utilizing category scores as a student diagnostic tool prior to curriculum development is appropriate for live, teacher-assisted classroom instruction as well as knowledge-based computer-assisted instruction.

Scoring Student-Generated Concept Maps in Introductory College Chemistry

INTRODUCTION

A concept map is an hierarchical arrangement of concept names and conceptual relationships (Novak and Gowin, 1984). Researchers have used the student-generated concept map as a diagnostic tool to evaluate student understanding of science (Moreira, 1987; Ault, Novak and Gowin, 1988; Brody, 1989). Previous analyses of students' maps have been primarily qualitative. Researchers have attempted to determine what it is the student knows, or thinks s/he knows, by discussing the student's map during clinical interviews. Ankney and Joyce (1974) claimed that interviews with students are a source of variance however.

Many researchers believe the student-prepared, domain-specific concept map is a viable tool for interpretation of student understanding in physics, biology, and chemistry (Moreira, 1987; Cleare, 1983; Brody, 1989). A concensus is missing however, on how to evaluate the novice map. Some educators have developed scoring protocols for student-generated concept maps (Cleare, 1983; Wallace and Mintzes, 1990). The methodology requires a map evaluator to award points for particular map characteristics. Research by Smith (1975), Ausubel (1968), Alverez and Risko (1987), Novak and Gowin (1984), and Brody (1989) suggest that the cognitive processes of categorization, class includion, progressive differentiation, and integrative reconciliation are represented by a student's concept map. Successful quantitative evaluation of student concept maps may reveal significant information about student cognitive orientation toward learning science.

This study describes a quantitative scoring methodology supported by current learning theory. The topic of chemical reactions (with concepts and propositions related to chemical change) was selected because it provides a primary focus in first year college chemistry courses. Burton (1988) suggested a domain-specific concept map is a product of the preparer's decision-making processes employed t learn that subject. Consequently, this study hypothesized that scores of concept maps for chemical reactions reflect traits students exhibit when learning chemistry.

METHOD

This study investigated the association between student concept map scores in chemistry and learning traits (independent variables). The amount of content information a student possesses and the level of reasoning ability a student exhibits in the domain are examples of characteristics which influence meaningful learning of chemistry. It is possible that one formal reasoner in chemistry may design a map incorporating multiple strands and few, yet sophisticated propositions. Another formal reasoner however, may embed many concepts within one major hierarchy, not categorizing into simpler, separately functioning "mini-hierarchies" (strands). In contrast, a third student, a concrete reasoner, may prepare a concept map much less intricate than either of these examples.

Data was collected over a period of eight weeks in the fall semester of 1989. Sixty-five students participated in the study. Each student was enrolled in a four year technical engineering college program. All subjects initially were inexperienced with concept mapping technique. All students participated in introductory activities, mapping concepts related to their engineering degrees. Sixty-one of the 65 participants were male and ranged in age from 19 to 26 years.

Upon completion of the introductory exercises, students were instructed to map a predetermined list of concepts related to chemical reaction equations and chemical change (see Figure 1: *Concept Mapping in Chemistry*). The student-generated concept maps in chemistry were then scored. During this same period, the subjects were assessed for chemistry content knowledge, cognitive reasoning in science, preferred learning style, creative and critical thinking, attitude toward chemistry, and demographic background.

General misconceptions of content were measured by the American Chemistry Society's (ACS) chemistry achievement test *High School Chemistry -Form 1987.* The *Group Assessment of Logical Thinking* (GALT) evaluated student cognitive reasoning capability in science. A student's inherent learning style was determined by Kolb's *Learning Style Inventory* (LSI). Creative and critical thinking skills were measured as a subtest of *GALT.* Wainwright's *Attitude Toward Chemistry* (1985) established a student's affect for the subject. Also, the subjects completed a questionnaire called *Individual/Demographic Data.*

An expert (criterion) map served as a template for scoring student-generated concept maps (see Figure 2: *Expert Map*). A panel of three college chemistry professors developed the expert map. Evaluators of student maps compared novice hierarachical structures and propositions to those represented by the experts' template. (See Figures 3a and 3b for samples of student-generated maps.) Construct validity of student maps was determined by the degree of appropriateness of the hierarchical structures and propositions presented.

The prescribed scoring methodology for evaluation of student-generated concept maps in chemistry focused on three components: (1) physical (hierarchical) structure of the map, (2) identified propositions, and (3) the actual validity versus implied validity of these components. Hierarchical structure and propositional validity were further defined and evaluated by examining specific map constructs.

Student-generated concept maps were scored by first identifying the following map constructs (see Figure 4: *Concept Map Scoring Form*):

- Total Number of Vocabulary Incorporated Into the Map
- Number of Hierarchical Levels
- Ratio of Number of Vocabulary to Number of Hierarchical Levels
- Number of Connecting Lines Drawn
- Number of Connecting Lines Validly Labeled
- Ratio of Connecting Lines Validly Labeled to Number of Connecting Lines Drawn
- Number of Strands Recognized Within the Map
- Number o Cross-Links Between Strands

The overall concept map score X is represented mathematically with the formula adjusted for discrete cognitive structuring differences. $X = [x-n(b+c)] + b/c$, where:

- x = initial tally of points (ratios) awarded for recognition of hierarachical, propositional and validity constructs on concept map.
- n = number of strands in concept map.
- b = summed ratios of number of vocabulary terms to number of hierarchical levels (per strand).
- c = summed ratios of number of valid connecting lines to total number of connecting lines drawn.

The term "$n(b+c)$" adjusted the initial concept map point tally to accommodate scoring maps in which students incorporated multiple strands that were weak conceptually or developed poorly. The ratio "b/c" tabulates strong student proficiencies in categorization and progressive differentiation skills. Students who incorporate an extensive number of vocabulary terms per hierarchical level, and illustrate a strong ratio of valid connecting lines to total number of lines drawn, acquire additional points. Map scores for chemical reactions were then correlated to the independent variables using ANOVA.

RESULTS

Overall concept map scores and concept map category scores were compared to the validated measures of student learning traits in chemistry. Significant correlations resulted.

Overall Concept Map Scores

Amount of Chemical Information Possessed By Student and Student Cognitive Reasoning Ability: Significant positive correlation existed between standardized ACS chemistry test scores and students' overall concept map scores. Results suggested that the higher the overall concept map score for chemical reactions the greater the amount of chemical knowledge possessed. Analysis of variance in overall concept map score to *GALT* categorical data (formal, transitional and concrete reasoning) also indicated the greater the overall concept map score the more formal the student's cognitive ability in science. See Table1 and Table 2. (The study ranked standardized scores to allow for analysis of variance of between-group and within-group means.)

Table 1

One Factor ANOVA X_1: ACS Category Y_1: CM Formulated/Z

Analysis of Variance Table

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	4	899.983	224.996	3.681
Within groups	59	3605.955	61.118	p = .0096
Total	63	4505.938		

Model II estimate of between component variance = 40.969

Table 2

One Factor ANOVA

X_1: Galt Category Y_1: CM Formulated/Z

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:
Formal vs. Transitional	10.772	3.616*	31.338*
Formal vs. Concrete	18.344	5.129*	45.175*
Transitional vs. Concrete	7.573	5.219*	7.434*

* Significant at 99%

Based on the initial findings above, this study postulated that high chemical knowledge scores reflect formal reasoning in chemistry. Further investigation was pursued to determine if an overall concept map score was simply a summation of the two traits. Analysis of variance in *GALT* score as correlated to chemical knowledge was significant ($p = .0035$). However, the variance in *GALT* was significant only between the very high ACS scorers and all other participants.

It appears that the highest overall concept map scores belonged to those students who reason formally about a very large amount of chemical information. The lowest overall concept map scores belonged to those students who reason concretely about a very small amount of chemical information. The students who reason formally about small amounts of chemical information, and the students who reason concretely about large amounts of chemical information were not significantly identified by overall concept map scores.

<u>Student Learning Style in Chemistry</u>: Overall scores of concept maps for chemical reactions were successful in identifying two of the preferred learning styles investigated. *Accommodators* and *assimilators* in chemistry displayed significant differences in the construction of concept maps for chemical reactions. Students who

obtained a very high overall concept map score prefer to learn chemistry through assimilation. The students who obtained a very low overall concept map score prefer to learn chemistry through accommodation. A student's preferred learning style in a domain depends on the extent s/he integrates such behaviors as concrete experience, reflective observation, abstract conceptualization, and active experimentation when learning. A student may be categorized an accommodator, diverger, converger, or assimilator (Kolb).

Concept Map Category Scores

Students who reason formally about a small amount of chemical information, and students who reason concretely about a large amount of chemical information were not identified by overall scores of concept maps for chemical reactions. Category scores of individual components of the concept map however did describe these students' learning traits in chemistry.

Propositional Validity: Sixty-seven percent and 44% of the students who scored very high and high (respectively) in the map category for propositional validity exhibited formal reasoning skills in chemistry. Eighty-one percent of the students who scored low and very low in the propositional validity category exhibited concrete reasoning in chemistry. Transitional reasoners in chemistry were not significantly identified by the concept map subscore of "propositional validity."

The ratio of number of validly labeled connecting lines to total number of connecting lines drawn measured the "propositional validity" of a concept map. Students who scored high in the category of propositional validity were significantly identified as formal reasoners in chemistry, independent of the amount of chemical information possessed. The concrete reasoners in chemistry illustrated low propositional validity on concept maps for chemical reactions, again independent of the amout of chemical information possessed.

A high category score for propositional validity also suggests that the map preparer prefers to learn chemistry through assimilation. The student appears to combine strengths of abstract conceptualization and reflective observation to organize a wide range of information into concise, logical form (Kolb). This student's map displays large numbers of concepts embedded within few hierarchical levels. Insightful and creative associations between concepts are identifiable. Propositional validity of this map is high.

In contrast, the student who prefers to learn chemistry through accommodation scores low in the concept map category of propositional validity. This student seeks concrete experiences and active experimentation (Kolb). Data reveal that this map preparer uses only a few concept names in each hierarchical level and frequently omits verb/verb phrases on connecting lines. Relationships between concepts are ambiguous. Propositional validity of this concept map is low.

Hierarchical Ordering Within Sets of Concepts: The ratio of number of vocabulary utilized per hierarchical level (per strand) represented the physical structure of the student's concept map for chemical reactions. Significant variance existed between students who possess a high amount of chemical knowledge and students who possess a low amount of chemical knowledge. Significant variance in the structural component map score also existed between students who possess middle and low levels of chemical information.

Analysis of map subscores for structural ordering of concepts indicated that high scorers in this category were students who possess a greater amount of chemical information. Forty-six percent of the students who scored high for the ratio of number of vocabulary utilized per hierarchical level (per strand) scored high on the ACS chemistry test. A disproportionate number of students who scored middle, low, and very low for the structural ordering component scored in the middle range for amount of chemical information possessed (47%, 46%, and 66.6%, respectively).

Further analysis of student scores for the map category of structural ordering illustrated significant differences between student subscores and specific types of chemical misconceptions. The students who scored high on the component map score "structural ordering" not only possess greater amounts of chemical information, but the information possessed specifically represents introductory chemical concepts.

Strand Count: The concept map subscore "strand count" also identified student understanding of Introductory Chemistry concepts. Data suggest the more strands a student employs to embed ordered sets of concepts and propositions within his/her concept map the greater the student's understanding of Introductory Chemistry concepts as measured by the ACS standardized test. (Test items which illustrated Introductory Chemistry concepts include questions about the Law of Conservation of Mass; Avogadro's Number and the mole concept; and graphical representation of physical change [cooling curve].)

DISCUSSION

The purpose of this study was to describe student understanding of chemical change by scoring student-generated concept maps for chemical reactions. The scoring protocol developed successfully described student learning disposition in chemistry. Quantitative evaluation of student-generated concept maps enabes concept mapping to be used as a diagnostic tool to monitor and explore conceptual change.

Understanding how a student conceptualizes chemical ideas is necessary for successful remediation of misconceptions in chemistry. The ability to diagnose student understanding of chemical change is prerequisite to development of curricula for teaching chemical reactions and reaction equations. A practical application of this study's findings is the utilization of concept map category scores to make informed decisions about instructional design.

Educators in science may consult student concept map category scores to gain information about student cognitive reasoning ability, amount of information possessed, and the student's preferred learning style in the domain. Efffective educational programs which strive to remediate misconceptions about scientific knowledge must use this information to develop instructional strategies complementary to individual student learning traits. Utilizing concept map category scores as a student diagnostic tool prior to curriculum development is appropriate for live, teacher-assisted classroom instruction as well as knowledge-based computer-assisted instruction.

Figure 1

Concept Mapping in Chemistry

A. Below is a list of vocabulary related to chemical reactions, chemical reaction equations, and chemical change.

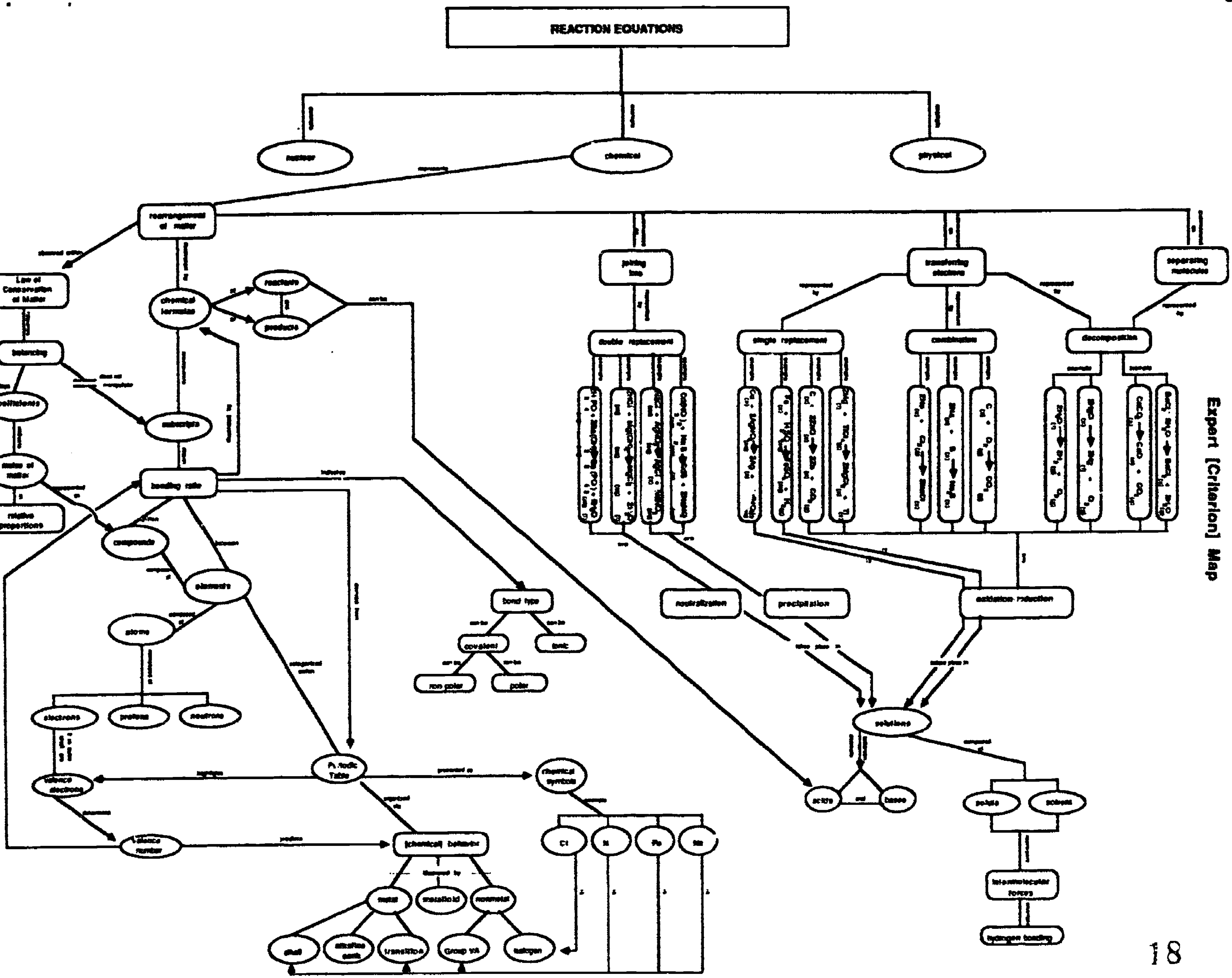
B. Map these concepts to produce a visual configuration of how you think about the words and the relationships between them.

C. A concept map represents conceptual organization of your thoughts and understanding of a subject. Remember to position object words and event words hierarchically, with more general, less specific concepts superordinate to more specific, less general ideas. Do not forget to clearly label all connecting lines: both cross-links between strands and propositional links within strands.

1. $2HgO \rightarrow 2Hg + O_2$
2. chemical reactions
3. neutralization
4. $2Na + S \rightarrow Na_2S$
5. combination/synthesis
6. chemical reaction equations
7. reactants
8. valence number
9. $2HCl + Mg(OH)_2 \rightarrow MgCl_2 + 2H_2O$
10. coefficients
11. solutions
12. Law of Conservation of Matter
13. subscripts
14. bases
15. compounds
16. double replacement
17. $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$
18. chemical formulas
19. products
20. rearrangement of matter
21. acids
22. transferring electrons
23. decomposition
24. $CaO + CO_2 \rightarrow CaCO_3$
25. joining ions
26. relative mole ratio
27. oxidation-reduction
28. single replacement
29. separating molecules
30. balancing/balanced
31. $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$
32. atoms
33. elements
34. oxidation state
35. $BaCl_2 \cdot 2H_2O \rightarrow BaCl_2 + 2H_2O$

ID. # ____________________

Page 12



Expert [Criterion] Map

Figure 3a

Sample I: Student-Generated Concept Map (Radial Construction)

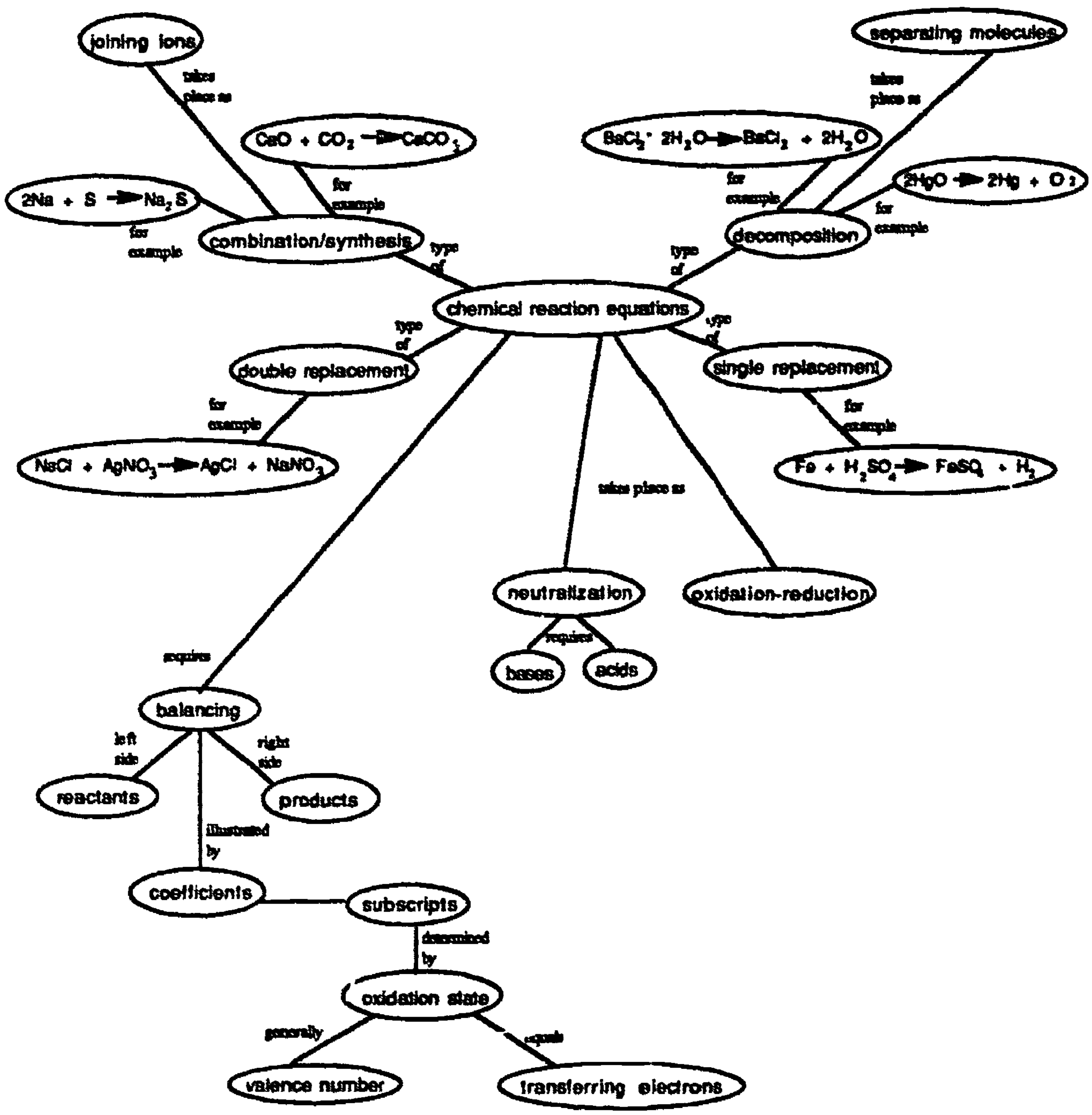


Figure 3b

Sample II: Student-Generated Concept Map

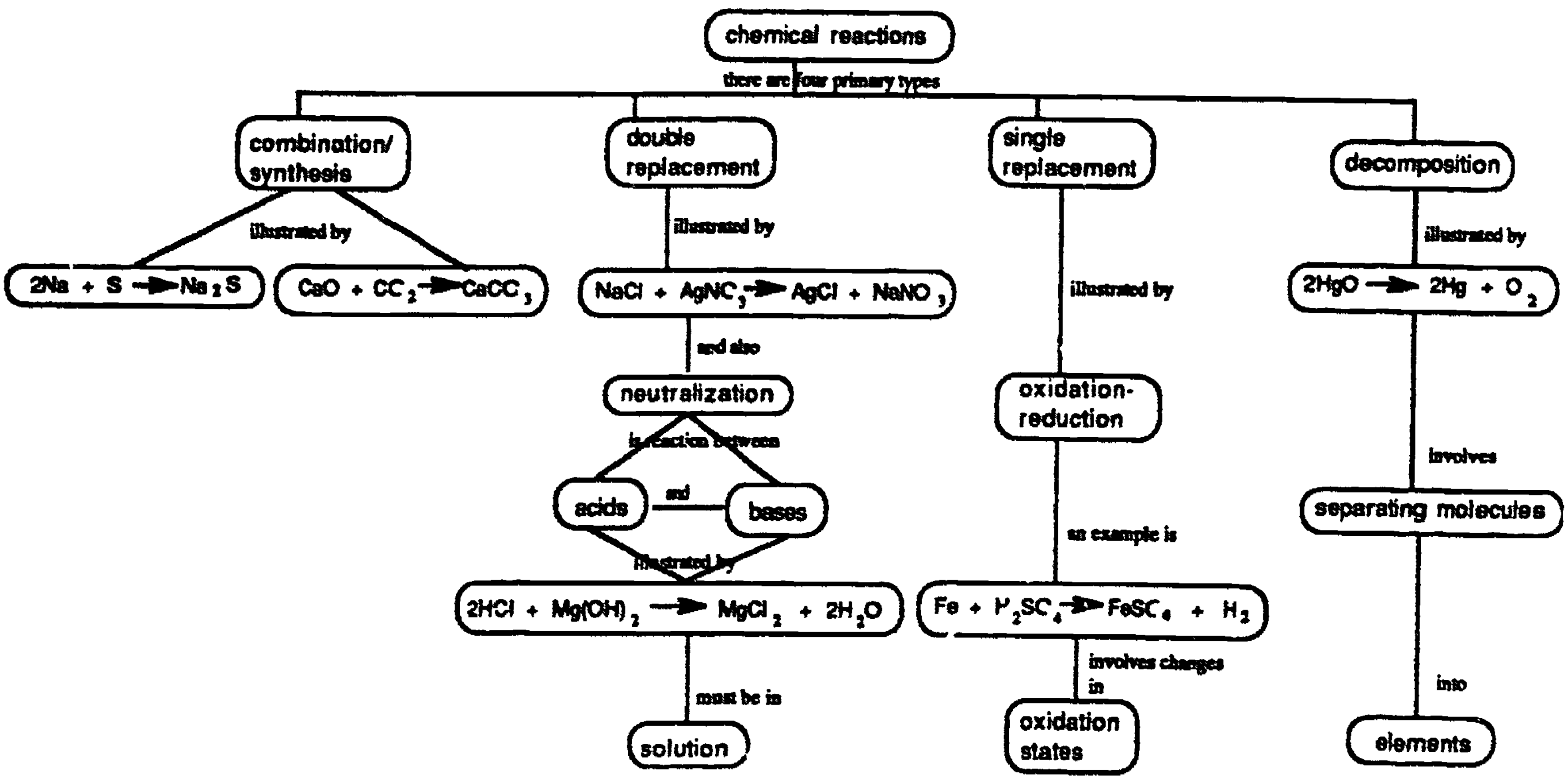


Figure 4

CONCEPT MAP SCORING FORM

1. **NUMBER OF Strands**: ________
(Strand recognized only if two or more vocabulary words are positioned in 85% of the hierarchical levels.)

2. **NUMBER OF CROSS-LINKS BETWEEN DIFFERING STRANDS**
(a) Drawn: ________
(b) Validly Labeled: ________

3. **NO. OF VOCABULARY**
(Per Strand)
(a) Strand One : ________
(b) Strand Two: ________
(c) Strand Three: ________

4. **NO. OF HIERARCHICAL* LEVELS**
(Per Strand) *Hierarchical Distinctions May Be Vertical, Horizontal or Radial.
(a) Strand One: ________
(b) Strand Two: ________
(c) Strand Three: ________

5. **RATIO OF NO. OF VOCAB:NO. OF HIER. LEVELS**
(Per Strand)
(a) Strand One: ________
(b) Strand Two: ________
(c) Strand Three: ________

6. **NO. OF CONNECTING LINES DRAWN**
(Per Strand)
(a) Strand One: ________
(b) Strand Two: ________
(c) Strand Three: ________

7. **NO. OF CONNECTING LINES VALIDLY* LABELED**
(Per Strand) *Validity established By Comparison of Student-Generated Map With Criterion Map.
(a) Strand One: ________
(b) Strand Two: ________
(c) Strand Three: ________

8. **RATIO OF CONNECTING LINES/ VALIDLY LABELED : DRAWN**
(a) Strand One: ________
(b) Strand Two: ________
(c) Strand Three: ________

9. **SUM OF RATIO'S**
(a) Cross-Link/Valid : Drawn ________
(b) Vocabulary : Hierarchical Levels (Summation of All Strands) ________
(c) Connecting Lines/Valid : Drawn (Summation of All Strands) ________
(d) Total Sum of Ratio"s ("a" + "b" + "c" = x) x = ________

10. **FINAL CONCEPT MAP SCORE "X'"**

$X = [x - n(b+c)] + b/c$ *

$X' = 10X + 50$

* "b", "c" and "x" Defined Above (#9)
"n" = Number of Strands (#1)

11. TOTAL NUMBER OF "EXAMPLES" IDENTIFIED: ________

BIBLIOGRAPHY

Alverez, Marino C. and Risko, Victoria (1987) Using vee diagrams to clarify third -grade students' misconceptions during a science experiment. Found in Volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics*. Eds Novak and Helm. Ithaca, NY: Cornell University. 6-14.

American Chemical Society (1987) ACS-NSTA Examination *High School Chemistry* Serial No. 51810. Prepared by the Examinations Institute of the Division of Chemical Education of the American Chemical Society.

Andersson, Bjorn (1986) Pupils' explanations of some aspects of chemical reactions. *Science Education* 70(5), 549-563.

Ankney, P. and Joyce, L. (1974) *The development of a Piagetian paper-and-pencil test for assessing concrete operational reasoning*. Unpublished doctoral dissertation: University of Northern Colorado.

Ault, Charles R., Novak, J.D. and Gowin, Bob (1988) Constructing vee maps for clinical interviews on energy conservation. *Science Education* 72(4), 515-545.

Ausubel, David (1968) *Educational Psychology: A Cognitive View.* New York: Holt, Rinehart and Winston.

Ausubel, David (1983) *The Psychology of Meaningful Verbal Learning.* New York: Grune and Stratton.

Baker, Duncan C. (1987) Some perspectives on the teaching of mathematics and natural sciences in an engineering curriculum. Found in Volume III of the *Proceedings of the International Seminar on Misconcpetions in Science and Mathematics* Eds Novak and Helm. 9-16.

Beyerbach, Barbara and Smith, Joyce (1990) Using a computerized concept mapping program to assess preservice teachers' thinking about effective teaching. *Journal of Research in Science Teaching* 27(10), 961-971.

Bourque, Donald and Carlson, Gaylen (1987) Hands-on versus computer simulation methods in chemistry. *Journal of Chemical Education* 64(3), 232-234.

Brasell, Heather (1987) The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching* 24(4), 385-395.

Brody, Michael, Kopec, Danny and Latour, Larry (1989) Towards an expert/novice learning system with application to infectious disease. *SIGART Newsletter.* April: Special Issue on Knowledge Acquisition.

Burton, Richard R. (1988) The environment module of intelligent tutoring systems. In *Foundations of Intelligent Tutoring Systems*. NJ: Lawrence Erlbaum Associates Publishers. 105-122.

Cachapuz, A. F. and Martins, I. P. (1987) High school students' ideas about energy of chemical reactions. Found in Volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics.* Eds Novak and Helm. 60-68.

Campbell, D. T., and Fiske, D. W. (1959) Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin* 56:81-105.

Carter, Carolyn and Bodner, George (1987) How student conceptions of the nature of chemistry and mathematics influence problem solving. Found in Volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 69-83.

Cleare, Catherine C. (1983) Using concept mapping to detect interventions effective in improving pre-service elementary education majors' understanding of science topics. Found in Volume I of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 156-159.

Cronbach, L. J., and Meehl, P. E. (1955) Construct validity in psychological tests. *Psychological Bulletin* 52:281-302.

diKleer, J. and Brown, J. S. (1981) Mental models of physical systems and their acquisition. In Anderson, J. R. (Ed) *Cognitive Skills and Their Acquisition* NJ: Lawrence Erlbaum.

diSessa, Andrea A. (1987) The third revolution in computers and education. *Journal of Research in Science Teaching* 24(4), 343-367.

Driver, R. and Erikson, G. (1983) Theories in action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education* 10, 37-60.

Ellerton, Nerida F. and Ellerton, H. David (1987) Mathematics and chemistry problems created by students. Found in Volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 131-136.

Feldsine, J. N. (1983) Conceptual mapping: A method for detection of possible student misconceptions. Found in Volume I of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 467-472.

Fowler, Thaddeus W. and Jaoude, Saouma Bou (1987) Using hierarchical concept/proposition maps to plan instruction that addresses existing and potential student misunderstandings in science. Found in Volume II of the *Proceedings of the International Seminar on Misconceptions in Science and MAthematics* Eds Novak and Helm. 138-142.

Good, Ron (1987) Artificial intelligence and science education. *Journal of Research in Science Teaching* 24(4), 325-342.

Hawkins, Jan and Pea, Roy D. (1987) Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching* 24(4), 291-307.

Herron, J. Dudley (1975) Piaget for chemists. *Journal of Chemical Education* 52(3), 146-150.

Jacobsen, Eggen, Kauchak, and Dulaney (1981) *Methods for Teachers: A Skills Approach* Columbus, OH: Charles E. Merrill Publishing Co.

Jenkins, J. R. and Jenkins, L. M. (1987) Making peer tutoring work. *Educational Leadership* March:64-68.

Kolb, D. A. (1981) *Learning Styles Inventory*. Massachusetts: McBer and Company.

Kopec, Danny, Latour, Larry, and Brody, Michael (1989) Towards an expert/novice learning system with application to infectious disease. *SIGART Newsletter.* April: Special Issue on Knowledge Acquisition.

Mann, R. E. (1977) Comprehension monitoring: Developmental and educational issue. In S. R. Chipman, J. W. Segal, and R. Glaser (Eds) *Thinking and Learning Skills: Research and Open Questions.* 2, 275-290. Hillsdale, NJ: Erlbaum.

McDermott, L. C. (1984) Research on conceptual understanding in mechanics. *Physics Today* July: 24-32.

Moreira, Marco A. (1979) Concept maps as tools for teaching. *Journal of College Science Teaching* 8(5): 283-286.

Moreira, Marco Antonio (1987) Concept mapping as a possible strategy to detect and to deal with misconceptions in physics.Found in Volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 352-360.

Novak, Joseph D. (1983) Can metalearning and metaknowledge strategies to help students learn how to learn serve as a basis for overcoming misconceptions? Found in Volume I of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Helm and Novak. Ithaca, New York: Department of Education. Cornell University. 100-111.

Novak, J., Gowin, D., and Johansen, B. (1983) The use of concept mapping and knowledge vee diagrams with junior high science students. *Science Educaion* 67(5), 625-645.

Novak, Joseph D. and Gowin, D. Bob (1984) *Learning How to Learn.* Cambridge University Press. Cambridge, Massachusetts.

Okebukola, Peter Akinsola (1986) The influence of preferred learning styles on cooperative learning in science. *Science Education* vol 70, no 5, 509-517.

Padilla, M., Okey, J. and Dillashaw, F. (1983) The relationship between science process skills and formal thinking abilities. *Journal of Research in Science Teaching*. 20, 239-246.

Reif, F. (1987) Instructional design, cognition, and technology: Applications to the teaching of scientific concepts. *Journal of Research in Science Teaching* 24(4), 309-324.

Ringnes, Vivi (1987) "Misconceptions in Environmental Chemistry Among Norwegian Students." Found in volume III of the *Proceedings of the International Seminar on Misconceptions in Science and Mathematics* Eds Novak and Helm. 415-421.

Roadrangka, V., Yeany, R. H. and Padilla, M. J. (1983) The construction and validation of group assessment of logical thinking (GALT). Paper presented to NARST Annual Meeting. Dallas, TX: April.

Schreiber, D.A. and Greenler, Mildred (1989) Unpublished: Development of Criterion [Expert] Map for Chemical Reactions.

Smith, Frank (1975) *Comprehension and Learning*. New York: Holt, Rinehart and Winston.

Stewart, J., Van Kirk, J., and Powell, R. (1979) Concept maps: A tool for use in biology teaching. *The American Biology Teacher* 41(3), 171-175.

Strike, K. A. and Posner, G. J. (1982) Conceptual change and science teaching. *European Journal of Science Education* 4, 231-240.

Verduin, Miller and Greer *Adults Teaching Adults* LC 5219 V46

Wainwright, Camille L. (1985) The effectiveness of a computer-assisted instruction package in supplementing teaching of selected concepts in high school chemistry: Writing formulas and balancing chemical equations. Paper Presented to the Annual Meeting of the National Association for Research in Science Teaching (ED257650). April 16, 1985.

Wallace, Josephine and Mintzes, Joel (1990) The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching* 27(10), 1033-1052.