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The Predictive Validity Of Concept-Mapping: Relationships To Measures Of Achievement

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ABSTRACT

Relationships between structural characteristics of 120 year twelve chemistry students' concept maps about chemical equilibrium and independent measures of achievement are examined in this paper. Fifty students in 1991 and seventy students in 1992 (all without experience of the technique) completed the task using twenty-four concepts. Non-metric multidimensional scaling was used to represent the maps as points in three-dimensional space, based on presence or absence of paired propositional links. Separation between maps reflected hierarchical structure, but also independent measures of student achievement. Canonical correlation analysis of the first data set revealed significant relationships between the MDS coordinates and independent measures of achievement on tests of knowledge and application process. Multiple regression analysis of the second data set against students' percentile rank scores on a national chemistry quiz revealed significant relationships. The results are interpreted as revealing structural differences in conceptual organization about chemical equilibrium among students with different levels of relative expertise in the domain. The significant relationship between map structure and cognitive process scores in chemistry also supports the view that the organization of knowledge influences its accessibility in cognitive tasks.

INTRODUCTION

The functional relationship between the organizational structure of domain specific knowledge and higher-order cognitive processes has been a matter of debate for twenty years. Bower (1972) argued that understanding is a function of the structural relationships between units of conceptual knowledge, and Bereiter & Scardamalia (1986) suggested that the construction and organization of conceptual networks within a domain of knowledge may provide the key to the nature of understanding and processes of higher order cognition within that domain.

In studies of cognitive processes in physics Chi, Feltovich & Glaser (1981), Chi, Glaser & Rees (1981), Eylon & Reif (1984) and de Jong & Ferguson-Hessler (1986) have supported the existence of a relationship between organizational attributes of the knowledge base and success at problem solving tasks. Chi, Feltovich & Glaser (1981) further claimed that there are differences between the knowledge structures of experts and novices within a domain of knowledge.

Studies of the organizational or configural properties of knowledge structures within a domain have been conducted using many different techniques (Shavelson & Stanton, 1975; Champagne, Klopfer, Desena & Squires, 1981; Naveh-Benjamin, McKeachie, Lin & Tucker, 1986; Durso & Coggins, 1990). Within science education, the technique of concept mapping (e.g. Novak, 1984, 1990) has helped to elucidate the nature of knowledge structures in different branches of science. In recent years the technique been used as a research tool to document conceptual change in areas of science (Wallace & Mintzes, 1990; Novak & Musonda, 1991). Used as a learning strategy intervention, concept mapping has been shown to have a significant relationship to achievement gains in physics (Pankratius, 1990) and in biology-related achievement of students in cooperative learning groups (Okebukola, 1992). Novak, Gowin & Johansen (1983, p.34) reported finding "that concept map scores correlate poorly with standardized test scores for typical classroom tests, but substantially with tests of transfer problem solving."

Wilson (in press) used multivariate techniques to investigate structural differences in 50 concept maps relating to chemical equilibrium drawn by upper secondary chemistry students. Presence and absence of linked pairs of concepts in the pooled data were used to construct a proximity matrix which was then analysed by non-metric multidimensional scaling (MDS). The scaling solution revealed separation between maps which apparently reflected independent measures of students' achievement in Chemistry, but also reflected the degree of hierarchical structure in the concept map.

This paper reports the results of an extension to the previous study in which the previous data are replicated using a further sample of 70 students. The question of whether concept maps predict traditional achievement scores in Chemistry will be explored by examining the statistical relationship between maps as coordinate locations in the MDS solution and independent measures of student achievement.

METHOD

Subjects

Concept maps about chemical equilibrium were prepared by a total of 120 year 12 chemistry students (with average age of 17.5 years). Fifty students from two schools (A & B) in 1991 and a further 70 students from three schools (B, C & D) in 1992 participated. All four institutions were private secondary colleges with very high proportions of the year 12 chemistry students proceeding to university entrance.

Procedure

The procedure is described in detail by Wilson (1990 & in press). All students were asked to prepare a concept map to best represent their understanding of the topic chemical equilibrium. Each class had completed a three-week curriculum unit on the topic in the previous lesson. The procedure followed was based on that of Novak & Gowin (1984) and the researcher modeled the procedure using concepts drawn from an unrelated domain before participants commenced the task. Participants were given an envelope containing twenty four concept labels (Table I) related to the topic (each label typed on a small piece of paper). All maps were completed within a 60 minute lesson. Students were asked to follow four directions; to place the most inclusive concept at the top of the map, to rearrange the concept labels until their placement best represented the participant's understanding of relationships between the nominated concepts; to glue the labels to a sheet of paper and to draw labeled arrows to represent the relationship between pairs of concepts. Figure 1 illustrates the concept map drawn by a 1992 student with very high achievement scores in all aspects of chemistry assessment.

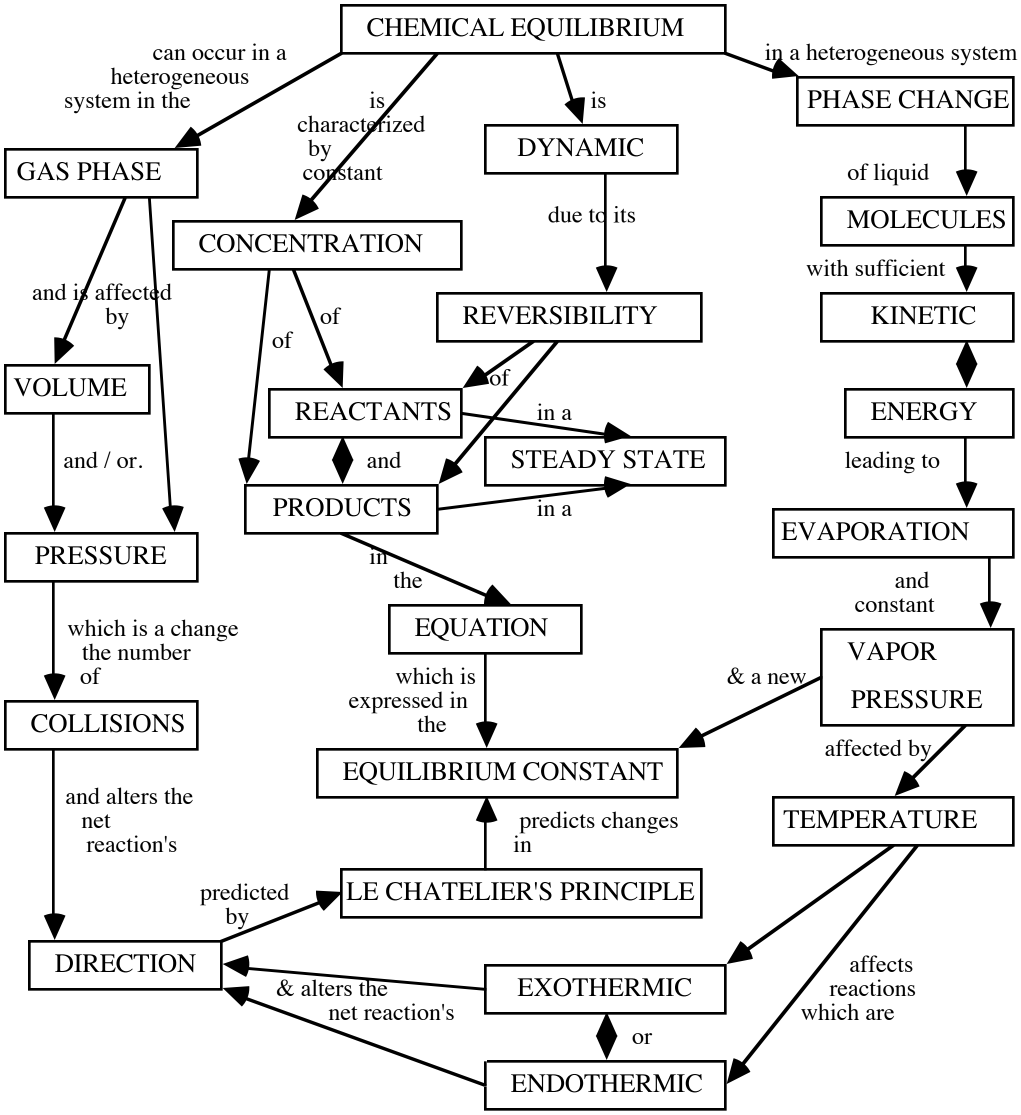

Figure 1. A concept map drawn by a student in 1992.

<u>Concepts</u>

Twenty-four concepts were chosen (Table I) from those specified in the syllabus for Senior Chemistry as prescribed by the state board which is responsible for accreditation of curriculum programs and monitoring of school based assessment for years 11 and 12, the two years preceding university entrance. Twenty concepts were the same in both years with four of the original replaced in the second year.

Table 1 Concepts used in the Concept-mapping Task

(a) 1991

chemical equilibrium	steady state	solubility
condensation	volume	temperature
equilibrium constant	phase change	ions
endothermic	vapor pressure	reversibility
Le Chatelier's Principle	evaporation	pressure
exothermic	molecules	concentration
gas phase	products	direction
equation	dynamic	reactants

(b) 1992

chemical equilibrium	steady state	**collisions**
kinetic	volume	temperature
equilibrium constant	phase change	**energy**
endothermic	vapor pressure	reversibility
Le Chatelier's Principle	evaporation	pressure
exothermic	molecules	concentration
gas phase	products	direction
equation	dynamic	reactants

Achievement measures used

(a) School assessment.

The student achievement measures obtained in 1991 were based on a variant of criterion-based school assessment known as standards-based assessment which is monitored by a state board (Board of Senior Secondary School Studies, 1987). Four performance dimensions were assessed. These were (1) content (recall of knowledge of content), (2) application process (understanding demonstrated by the ability to apply knowledge in simple and complex situations), (3) scientific process (use of scientific processes in dealing with experimental results and other data), and (4) laboratory skills. Students' percentage scores on tests of recall of content knowledge, and application of knowledge are illustrated in Figures 2a& b respectively. The ability to apply recalled knowledge is tested through simple, single step numerical exercises and also through novel and complex multi-step problem solving tasks.

Because of the school-based nature of assessment within the state, students results were obtained from a non-uniform procedure using different test items, however, comparability of standards is monitored by the state authority. Despite the possible influence of differences in testing standards on the data, tests revealed no significant differences between the means of distributions of test scores in schools A and B. The level of difficulty of test items used in the two schools was very similar.

(b) Percentile rank scores on a national chemistry quiz.

To avoid the potential influence of differences in testing standards between schools referred to above, a standardized and independent measure of conceptual knowledge was applied in 1992. The measure of achievement used as the dependent variable in multiple regression analysis was percentile rank score on the Australian National Chemistry Quiz. The Chem Quiz sponsored by the Royal Australian Chemical Institute has been described and discussed by Walding, Fogliani, Over, & Bain (in press). Results from the 1992 Chem Quiz are shown in (Figure 3). Scores were available for only 61 of the 70 students and only these cases have been used in the regression analysis.

<u>Data Analysis</u>

Initially, multidimensional scaling was used to ordinate the subjects' concept maps as points in three dimensional space (Figures 2a, b & 3) and the three-dimensional coordinates from each analysis were used as the basis for the subsequent analyses, i.e., canonical correlation and multiple regression.

<u>Non-metric multidimensional scaling (MDS)</u>

Non-metric multidimensional scaling was used to represent the fifty-four individual maps as points in three-dimensional space using the SPSS for UNIX programs PROXIMITIES and ALSCAL (SPSS Inc., 1990). The concept map drawn by each participant was coded in the form of a twenty-four by twenty-four cell matrix, indicating the presence or absence of an arrow between pairs of concepts. All links between pairs of concepts were included, regardless of the label given to the relationship by the subject.

The matrices analyzed by MDS involved 50 and 70 cases, each with a row of 276 cells (24 x 23/2) with each cell representing the presence or absence of a link between two concepts in the map drawn by the individual. The binary matching coefficient DICE was used to compute proximity values between cases and the resultant proximity matrix was used as input to ALSCAL.

<u>Canonical correlation analysis</u>

To test whether pattern apparent in the first MDS solution (1991) from 50 maps was of statistical significance, canonical correlation analysis (Tabachnik and Fidell, 1989) using the MANOVA program of SPSS (SPSS Inc., 1990) was used to examine relationships between the MDS coordinates on the first three dimensions and the percentage test scores on recall of knowledge, application of knowledge and use of scientific processes obtained by the respective students.

Multiple regression analysis

Similarly, to test whether the spatial coordinates resulting from the second MDS analysis of 70 concept maps (1992) were related to students' percentile scores on the national chemistry quiz, multiple regression (SPSS REGRESSION) was applied using quiz score as the dependent variable on coordinates on the first three dimensions as independent variables.

RESULTS

Multidimensional Scaling Analysis of the Concept Maps

Figures 2a, b and 3 show the distribution of subjects' individual maps as points on the first two dimensions obtained from a scaling solution of three-dimensions. The numbers representing the spatial location of individual maps reflect the test score of that same student on the performance dimension specified in each figure. Coordinates for each map are used in a subsequent analysis. Fifty per cent of the variance in the 1991 data matrix is accounted for in three dimensions and the Kruskal stress value = 0.25. In the larger 1992 sample (N = 70) the explained variance was 37% with a stress value of 0.27. The low level of explained variance results from the large number of possible paired links which could be drawn in the concept maps.

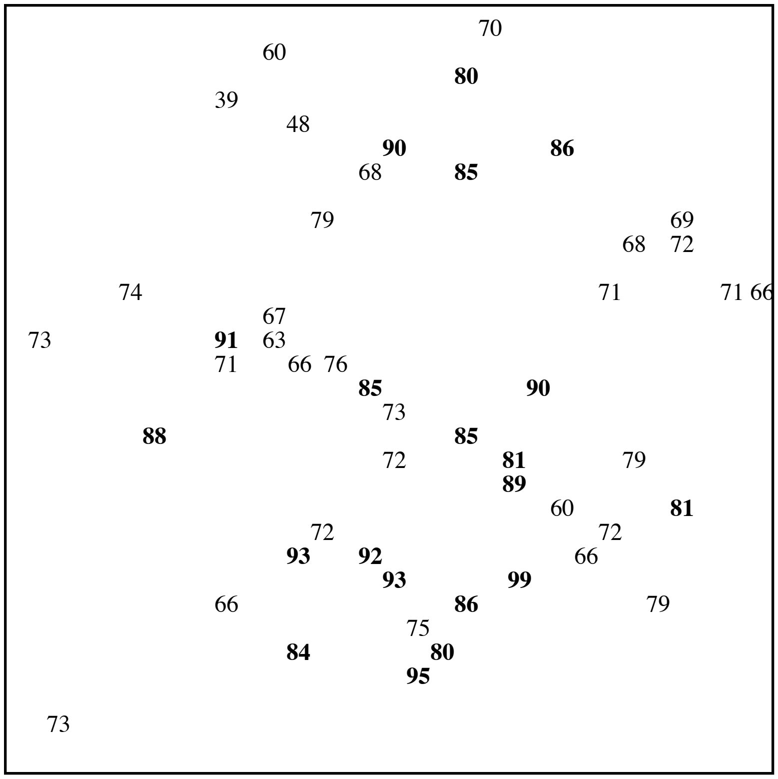

Figure 2a. Two dimensional plot (from MDS) of 1991 concept maps (N = 50). Dimension 1 (horizontal) vs Dimension 2 (vertical). Maps are located as points showing individuals' percentage score on tests of recall of knowledge. Scores of 80% or greater are shown in boldface type.

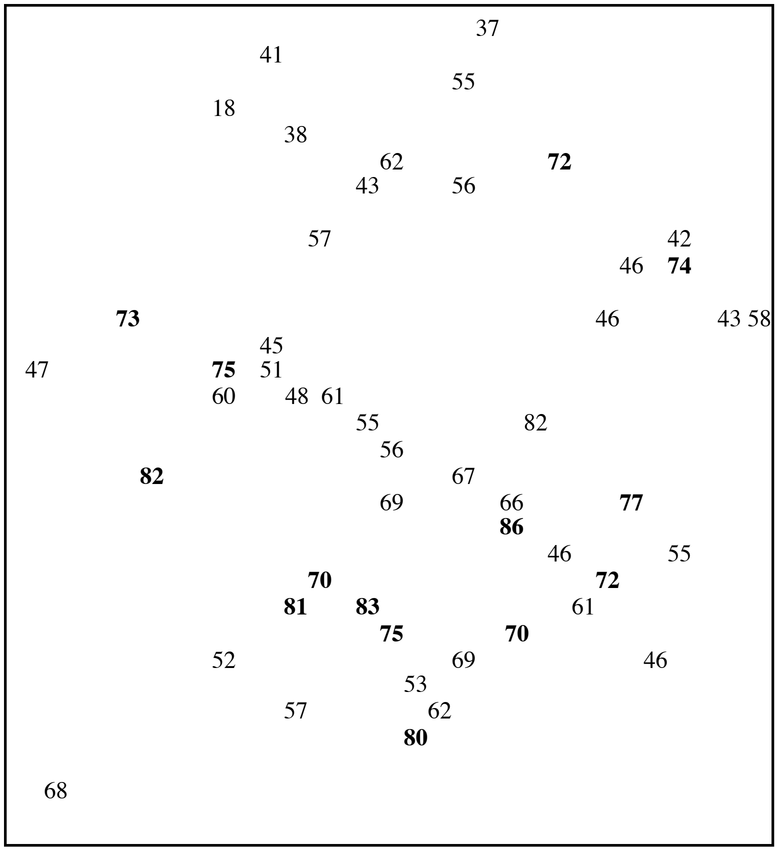

Figure 2b. Two dimensional plot (from MDS) of 1991 concept maps (N = 50). Dimension 1 (horizontal) vs Dimension 2 (vertical). Maps are located as points showing individuals' percentage score on tests of application process. Scores of 70% or greater are shown in boldface type.

In Figures 2a and 2b maps shown as points located in close spatial proximity, share a high proportion of identical paired relationships (Wilson, in press). Separation on the first (horizontal) dimension reflects differences in the initial (upper) levels of the concept maps while variation along the second (vertical) dimension reflects hierarchical organization and complexity. There is a gradation of students' scores along the second (vertical) dimension on tests of recall of knowledge and application of knowledge respectively in Figures 2a and 2b respectively.

Canonical correlation analysis

To determine whether the trends apparent in Figures 2a and 2b were of statistical significance, relationships between three test scores (1991) and the three MDS dimension coordinates were analysed using canonical correlation. No transformations were applied to the data and there was no missing data among the 50 cases. The canonical correlation for the first of canonical variate pair was 0.56 (90% of variance). The test of significance of the canonical correlation for the first canonical variate pair showed an F value of 2.31 ($p = 0.02$). The remaining two canonical correlations were less than 0.2 and were not significant. Data on the first canonical variate are presented in Table 2 below.

Table 2.
Correlations, standardized canonical coefficients, canonical coefficients, canonical correlation, percentages of variance, and redundancies between dimension variables and test score variables and the corresponding canonical variate.

	First canonical variate pair	
DIMENSION SET	Correlation	Standardized coefficients
Dim 1 (horizontal)	0.07	0.12
Dim 2 (vertical)	-0.99	-0.99
Dim 3	-0.09	-0.09
Per cent of variance	33%	
Redundancy	10%	
TEST SCORE SET		
Knowledge of content	0.76	0.58
Application process	0.91	0.85
Scientific process	0.33	-0.61
Per cent of variance	50%	
Redundancy	15%	
Canonical correlation 0.56; F = 2.31; p = 0.02		

Bivariate regression analysis for each of the dimension variables against each of the test score variables showed $t = -2.58$ (significance level = 0.01) for test score on application of knowledge with Dimension 2.

These results support statistically the earlier interpretation of the MDS output in which spatial location of individual concept maps was apparently related to the students' test scores.

In particular there is a significant relationship between position on Dimension 2 and test score on application of knowledge.

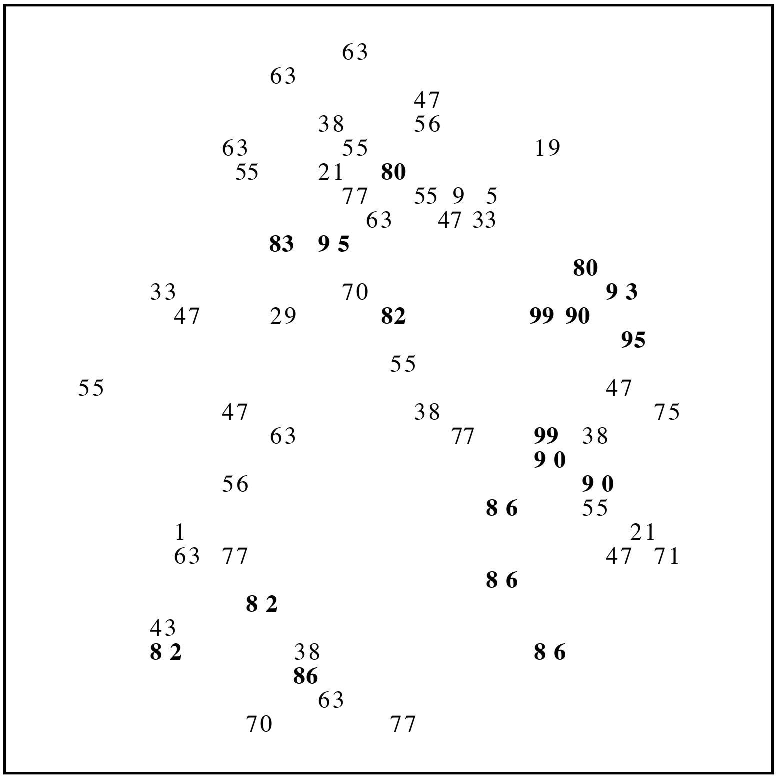

Figure 3. Two dimensional plot (from MDS) of 1992 concept maps (N = 70). Dimension 2 (horizontal) vs Dimension 3 (vertical). Maps are located as points showing individuals' percentile rank on the RACI Chem Quiz. Percentile ranks of 80 or more are shown in boldface type.

The MDS plot of Dimension 2 against Dimension 3 reveals a concentration of maps drawn by students with lower percentile ranks on the chemistry quiz in the upper left quadrant, with the majority of the maps drawn by students with a percentile ranks of 80 or more located below a diagonal from top right to bottom left of the figure. This suggests a relationship between percentile rank on the Chem Quiz and Dimension 3.

<u>Multiple regression analysis</u>

To determine whether the apparent relationship in the data presented above was of statistical significance, standard multiple regression was performed between the three dimensional coordinates as independent variables against the percentile rank scores as the dependent variable for the 1992 data set of 61 cases. Standardized scatterplots revealed no correlation among independent variables. Results of the analysis using SPSS REGRESSION show that coordinate location on the three dimensions significantly predicted the students' individual percentile rank. Table 3 displays the correlations between the variables, the unstandardized regression coefficients (B) and intercept, the standardized regression coefficients (β) and R, R^2, and adjusted R^2. R for regression was significantly different from zero, $F(3, 57) = 2.809$, $p < 0.05$.

Table 3.

Standard multiple regression of three dimension variables on percentile ranks

	Percentile rank	Dim 1	Dim 2	Dim 3	B	β
Dim 1	-0.14				-3.235	-0.138
Dim 2	0.20	0.02			4.870	0.201
Dim 3	-0.27	0.02	-0.02		-6.487*	-0.259
				Intercept =	61.589***	
Mean	61	-0.03	0.01	0.06	$R^2 = 0.13$	
Std. dev.	24	1.04	1.01	0.97	Adj. $R^2 = 0.08$	
					R = 0.36*	

* $p < 0.05$; ***$p < 0.001$.

The three dimensions in combination significantly predicted percentile rank and accounted for 12.8% of the variance in the data. Examination of the beta values for individual variables indicates a significant negative relationship between Dimension 3 and the dependent variable (r = -0.27). This result supports the trend apparent in the MDS plot of percentile rank scores on Dimensions 2 and 3 (Figure 3).

CONCLUSIONS

It is important to note that the students who participated in this study had no experience of the technique prior to the activity described herein. The organizational structure of knowledge relating to the topic of chemical equilibrium revealed in the concept maps was that of naive students, uninfluenced by prior training.

The results presented in this paper support the contention that concept maps can reveal qualitative information about the structure and organization of the knowledge base of the individual. The use of non-metric multidimensional scaling to ordinate maps as points in multidimensional space has facilitated the study of group cognitive structure through analysis of pooled data from a relatively large sample. Analysis by MDS converted proximity matrices to a set of coordinates on three dimensions and provided the basis for multivariate analyses of the data.

The question of whether a students' performance on a traditional Chemistry test can be predicted from a concept map is supported by both the analyses presented. Canonical correlation of the MDS coordinates from the 1991 data reveal that coordinate location was significantly related to performance on a test of ability to apply knowledge in simple and complex situations. Similarly, multiple regression analysis of the 1992 data set showed that coordinate location was a significant predictor of percentile rank on the national chemistry quiz, a test of conceptual knowledge.

DISCUSSION

The results of the canonical correlation analysis of the 1991 data that show a higher correlation of map coordinates with test scores on application of knowledge than with test scores on recall of knowledge, are consistent with results reported by Novak, Gowin & Johansen (1983, p. 34) in which they claimed that concept map scores correlate poorly with standardized test scores for typical classroom tests, but substantially with tests of transfer problem solving. Both sets of results suggest that the organizational structure of conceptual knowledge in memory influences its accessibility in higher-order cognitive tasks.

The methodology adopted in this study provides an alternative to the scoring procedure advocated by Novak (1984) and used by Novak & Musonda (1988). By analysing the presence and absence of all possible pairs of concepts, similarities in the patterns of paired linkages become an important factor in the multidimensional scaling analysis. Although the propositional labels given to paired relationships were not used in this study, the nature of the analysis is sensitive to unusual combinations. Infrequently observed pairs of concepts were often labeled by propositional links indicating the presence of a naive concept or "misconception."

"An important property of conceptual representations is their configural nature. If true, then it is the pattern of interrelationships among a set of concepts that should prove useful for differentiating among individuals with differing levels of knowledge," (Goldsmith & Johnson, 1990, p. 246). The techniques presented in this paper have differentiated among individuals and that differentiation has been shown to be derived from the conceptual interrelationships portrayed in individual concept maps. The results support the claims made by the author of the technique (Novak, 1984, 1990) that concept mapping gives researchers insight into the cognitive structure of the individual.

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