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Analyzing the Structure of Student Sustainability Knowledge Using Traditional and Holistic Concept Map Scoring Methods

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ABSTRACT

To properly initiate educational reforms needed to train sustainability-conscious engineers, methods are needed to assess conceptual understanding of sustainability. Concept maps (cmaps) have been proposed as useful tools for capturing the complexity and interconnectedness of sustainability; however, difficulties in scoring cmaps have limited their application as assessment tools. The goal of this project was to examine effectiveness of traditional and holistic cmap scoring approaches for characterizing student understanding of sustainability.

Cmaps were used to assess structure of student sustainability knowledge in a capstone design course and a graduate seminar in Civil and Environmental Engineering (CEE) at Georgia Tech. Judges applying traditional and holistic cmap scoring methods demonstrated at least substantial agreement ($\kappa_{Cohen} > 0.60$). Convergent validity was also shown for the two scoring approaches. Results of traditional and holistic procedures suggested that graduate students possess more sophisticated semantic networks related to sustainability than undergraduates. Data on CEE student sustainability knowledge can be used to guide efforts to integrate sustainability into undergraduate curricula. More broadly, study results demonstrate that cmaps can be used as valid and reliable assessment tools.

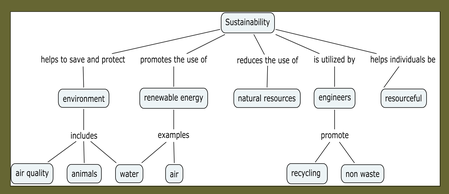

Figure A.1. Example student sustainability cmap (traditional scores: NC = 11, HH = 2, NCL = 1) (holistic scores: comp = 1, org = 1, corr = 3).

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INTRODUCTION

Sustainable Engineering: Although technology has contributed to current unsustainable practices, engineering is important for promoting future sustainable development. Sustainable engineering is a new field aimed at balancing economic, environmental, and social systems during development. To properly initiate educational reforms needed to train sustainability-conscious engineers, methods are needed to assess conceptual understanding of sustainability (Figure 1).

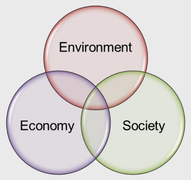

Figure 1. Conceptual sustainability model[1].

Concept Maps (Cmaps): Cmaps, which are graphical tools for organizing knowledge, may be useful tools for capturing the complexity of sustainability. Difficulties in scoring cmaps have limited their wide-spread application as assessment tools. Two potential scoring procedures include the traditional and holistic methods[2] (Figure 2).

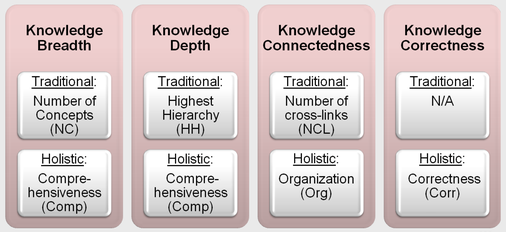

Figure 2. Traditional and holistic cmap scoring approaches[2].

OBJECTIVES

1. To determine the reliability and validity of traditional and holistic cmap scoring methods.
2. To analyze the ability of scoring approaches to discern differences in sustainability knowledge between undergraduates and graduates.
3. To provide insights for improving sustainability education in Civil and Environmental Engineering (CEE) at Georgia Tech using cmap data.

Theoretical Basis

Use of cmaps is supported by semantic memory theory, which posits that knowledge networks are formed by creating directed links between concepts. Since cmaps mimic internal semantic networks, they may be used to infer structure of student understanding[2].

EXPERIMENTAL METHODS

Student Populations: CEE students enrolled in capstone design ($n = 51$) course and a graduate transportation seminar ($n = 12$) participated in a cmap workshop where they created cmaps on the focus question: "What is sustainability?"

Traditional Cmap Scoring: Two expert judges quantified the number of concepts (NC), highest hierarchy (HH), and number of cross-links (NCL) to characterize breadth, depth, and connectedness of knowledge, as per Novak[2].

Holistic Cmap Scoring: Two expert judges characterized comprehensiveness, organization, and correctness of cmaps using a validated rubric developed by Besterfield-Sacre[2].

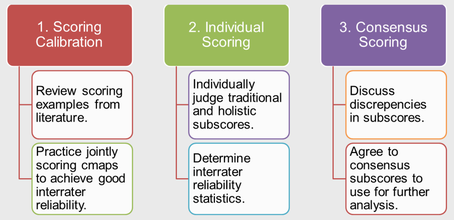

Figure 3. Methodology for scoring cmaps.

RESULTS AND DISCUSSION

Reliability: Both the traditional holistic scoring methods were highly reliable. Cohen's kappa, a very conservative measure of interrater reliability, was within the substantial agreement range ($0.60 < \kappa_{Cohen} \leq 0.80$)[3] for all sub-scores (Figure 4). Thus, properly-trained judges can be used to reliably score cmaps using either traditional or holistic scoring procedures.

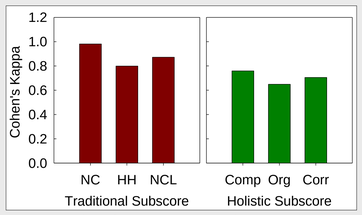

Figure 4. Interrater reliability of traditional and holistic scoring methods.

Validity: Spearman correlations between traditional and holistic subscores that quantify similar cmap characteristics (i.e. NCL and organization) and lack of correlations between subscores that quantify different cmap qualities (Table 1) suggest convergent validity for the two scoring approaches. Thus, both methods can be used to characterize breadth, depth, and connectedness of sustainability knowledge.

Table 1. Spearman correlations between traditional and holistic subscores.

	NC	HH	NCL
Comprehensiveness	0.476**	0.274*	0.223
Organization	-0.187	0.064	0.678**
Correctness	0.160	-0.079	0.006

RESULTS AND DISCUSSION (CONT.)

Traditional Method Outcomes: Graduate students had more sophisticated sustainability-related semantic networks than undergraduates. Graduate students included statistically more ($p = 0.024$) cross-links than undergraduates. Overall, total traditional scores for graduates were significantly higher ($p = 0.025$) than for undergraduates (Figure 5). Thus, the traditional method was able to differentiate between students with expert and novice sustainability knowledge.

Holistic Method Outcomes: Holistic scores also revealed graduates' sustainability knowledge networks to be more complex than those of undergraduates. Specifically, graduates' total holistic scores were significantly higher ($p = 0.027$) than undergraduates (Figure 6). Thus, the holistic method was also able to capture differences in student sustainability knowledge.

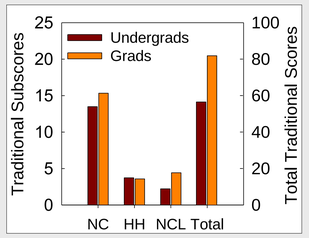

Figure 5. Undergraduate and graduate traditional cmap scores.

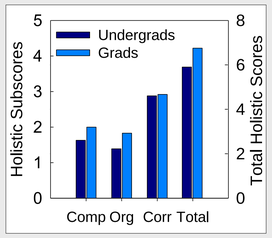

Figure 5. Undergraduate and graduate holistic cmap scores.

CONCLUSIONS

1. Cmaps can be reliably scored ($\kappa_{Cohen} > 0.60$) using traditional or holistic approaches by trained judges.
2. Both scoring procedures show convergent validity for quantifying knowledge depth, breadth, and connectedness in cmaps.
3. Both traditional and holistic scoring methods can discern differences in sustainability knowledge between undergraduates and graduates.
4. Since undergraduates had statistically fewer cross-links than graduates, improvements to CEE curricula may be needed to teach students about the interrelated nature of sustainability.

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3. Landis, J. R.; Koch, G. G., The measurement of observer agreement for categorical data. *Biometrics* **1977,** *33*, 159-174.