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Assessing and Improving Student Sustainability Knowledge in Civil and Environmental Engineering at Georgia Tech:

Using Concept Maps to Assess Structure and Content of Sustainability Knowledge

> Mary Katherine Watson Civil and Environmental Engineering March 9, 2012

Georgia Institute of Technology[®]



Presentation Outline

- Introduction
- Concept Maps
- Experimental Methods
- Results and Discussion
- Future Work
- Summary and Conclusions
- Questions



Introduction: Tragedy of the Commons

- "The Tragedy of the Commons" was a landmark manuscript published in *Science* in 1968.
- Tragedy of the Commons describes a phenomenon where individuals deplete limited shared resources, even though the resources are essential for survival.
- Global adoption of a sustainable development paradigm is an emerging strategy for combating the Tragedy.

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The Tragedy of the Commons

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Figure 1. "The Tragedy of the Commons" manuscript.

Introduction: Sustainable Development and Sustainability

• Sustainable development is

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- Johannesburg Declaration (2002) first proposed the three pillars of sustainable development.
- Pillars include economic development, environmental protection, and social development.



Figure 1. *Our Common Future*, which first articulated the popular definition for sustainable development (1987).



Figure 2. Three pillars of sustainable development.

Introduction: Sustainable Engineering Education

- Engineering is important for developing sustainable development strategies.
- For engineering to contribute to sustainability, sustainably-conscious engineers must be trained.
- Requires emphasis on systems and interdisciplinary thinking.
- Requires incorporation of sustainability concepts into engineering curricula.



Figure 3. Some organizations that have endorsed curricula reform.

Introduction: Sustainability Knowledge Assessments

- Effective methods for assessing student understanding of sustainability are needed to guide curricula reforms.
- By identifying areas of student proficiency and deficiency, educators can devise integration strategies (vertical and/or horizontal).
- Traditional assessments (i.e. objective tests) provide only a limited view of knowledge content and structure.
- Non-traditional assessment instruments that may be appropriate for sustainability assessments include journals, annotated portfolios, and concept maps (cmaps).

Introduction: Sustainability Knowledge Assessments

- Cmaps are graphical tools for organizing knowledge.
- Allow students to explicitly reveal knowledge content and structure.
- Appropriate because allow students to demonstrate inherent interconnectedness of sustainability concepts.
- Practical methods for scoring cmaps are needed before widespread application of cmap-based assessments.



Figure 4. Example of a simple student sustainability cmap.

Goal: To promote the use of cmap-based assessments for guiding and evaluating improvements in sustainability education.

To determine the reliability and validity of traditional, holistic, and categorical cmap scoring methods.

To analyze the ability of scoring approaches to discern differences in sustainability knowledge between undergraduates and graduates.

Objective 3

Objective 2

Objective 1

To provide insights for improving sustainability education in Civil and Environmental Engineering (CEE) at Georgia Tech and abroad using cmap data.

Concept Maps: Function and Structure

- Constructed by enclosing concepts related to a central topic in boxes.
- Connecting lines with linking phrases depict relationships between concepts.
- Cmap Components
 - Propositions
 - Hierarchies
 - Cross-links



Figure 5. Cmap components.

Concept Maps: Theoretical Basis

Cognative Psychology

- Semantic memory is an organized database of concept-based knowledge.
- Semantic memory theory posits that knowledge networks are formed by creating directed links between related concepts.
- Interconnectedness is a distinguishing characteristic of a expert semantic networks.
- Cmaps mimic structure of semantic networks.



Figure 6. Example of a simple student sustainability cmap.

Concept Maps: Use as Assessment Tools

All cmap assessments include a task, format, and scoring method.



Figure 7. Components of a cmap assessment.

Concept Maps: Scoring

Component-Level Method

- Also called the traditional method.
- Number of concepts represents knowledge breadth sub-score.
- Highest level of hierarchy represents knowledge depth.
- Number of cross-links represents knowledge connectedness.
- Can compute a total score by assigning weightings to each sub-score.

Knowledge Breadth	Knowledge Depth	Knowledge Connectedness
The number of concepts	The number of hierarchies	• The number of cross-links,
included in the cmap is	included in the cmap is	which create propositions
counted.	counted.	using concepts from different
No consideration given to	The highest level of	hierarchies, is counted.
quality or correctness of	hierarchy is recorded.	No consideration given to
concepts.		quality or correctness of
		cross-links.

Table 1. Components of traditional cmap score.

Concept Maps: Scoring

Map-Level Method

- Also known as the holistic method.
- Uses a rubric to rate the comprehensiveness, organization, and correctness of entire cmap on a 3-point scale.
- Comprehensiveness relates to knowledge depth and breadth.
- Organization relates to knowledge connectedness.



Concept Maps: Scoring

Category-Based Method

- Categorize concepts into 1 of 10 sustainability categories.
- Calculate category relevance (CR), which describes category most associated with sustainability.
- Calculate complexity index (CO), which describes interconnectedness between concepts from different categories.



Figure 9. Sustainability categories.

Concept Maps: Applications in Sustainability Education

- Cmaps have been widely applied in science education, but some authors have used them to assess sustainability knowledge.
- Segalas et al.⁴² investigated the effectiveness of six sustainability courses by comparing student cmaps before and after course delivery⁴².
- Borrego et al.⁴¹ analyzed cmaps before and after a green engineering course using the holistic scoring method.
- Use of cmaps as assessment tools are also suggested for characterizing student understanding of social sustainability in a sustainable construction course ⁴⁴⁻⁴⁶.

Research Methods: Student Populations and Data Collection

- Students from a CEE capstone course and a graduate-level seminar participated in a concept mapping workshop.
- Students trained to create cmaps using CmapTools through a short mini-lecture and completion of a practice cmap.
- At the end of the workshop, students created a cmap on the focus question: "What is sustainability?"



Figure 10. Sample student sustainability cmap.

Research Methods: Student Demographics

51 out of 66 capstone design students (77%) submitted cmaps. 12 out of 21 graduate transportation students (57%) submitted cmaps.

Table 3. Student demographics.

Description	Capstone Design (%) (n = 51)	Graduate Seminar (%) (n = 12)
Gender		
Male	81.3	58.3
Female	18.8	41.7
Major		
Civil Engineering	85.4	100
Environmental Engineering	14.6	0
Country		
United States	76.6	41.7
International	23.4	58.3
GPAª		
3.5 <u>< </u> GPA <u><</u> 4.0	35.4	100
3.0 <u>< </u> GPA < 3.5	31.3	0
2.5 <u>< </u> GPA < 3.0	18.8	0
2.0 <u>< </u> GPA < 2.5	14.6	0
GPA < 2.0	0	0

Research Methods: Judge Training and Scoring

Two expert judges were trained before scoring cmaps using traditional, holistic, and category-based scoring methods.



Figure 11. Methodology used to score cmaps.

Results: Traditional Scores

- Number of concepts (NC), indistinguishable between undergrads (13.49) and grads (15.33).
- Highest hierarchy (HH) not statistically different between undergrads (3.73) and grads (3.58).
- Grads included statistically more cross-links (NCL) (4.42) than undergrads (2.22) [F(1, 61) = 5.36, p = 0.025].





Grads have more connected sustainability knowledge than undergrads.

Results: Traditional Scores

Traditional method shown to have good inter-rater reliability and internal consistency.

 Table 4. Reliability of traditional scores.

	NC	HH	NCL
Cohen's kappa (unweighted)	0.981	0.799	0.872
Krippendorff's alpha (ratio)	0.999	0.961	0.960
Cronbach's alpha	1.00	0.970	0.976

- Cohen's kappa within "substantial" agreement range ($\kappa \ge 0.80$).
- Krippendorff's alpha within "adequately acceptable" range ($\alpha \ge 0.80$).
- Cronbach's alpha within "excellent" range ($\alpha \ge 0.90$).

Results: Holistic Scores

- Comprehensiveness indistinguishable between undergrads (1.63) and grads (2.00).
- Grad organization scores (1.83) at least marginally higher than undergrad scores (1.39) [p = 0.062].
- Correctness indistinguishable between undergrads (2.88) and grads (2.92).
- Total scores significantly higher for grads (5.75) than for undergrads (5.90) [F(1, 61) = 5.15, p = 0.027].



Figure 13. Holistic cmap scores.

Grads produced overall higher quality cmaps than undergrads.

Results: Holistic Scores

Holistic method shown to have good inter-rater reliability and internal consistency.

Table 5. Reliability of holistic scores.

	Comprehensiveness	Organization	Correctness
Cohen's Kappa (Unweighted)	0.759	0.649	0.705
Krippendorff's alpha (Interval)	0.833	0.836	0.675
Cronbach's Alpha	0.909	0.915	0.804

- Cohen's kappa within "substantial" agreement range ($\kappa \ge 0.80$).
- Most Krippendorff's alpha within "adequately acceptable" range ($\alpha \ge 0.67$).
- Cronbach's alpha within "good" range ($\alpha \ge 0.80$).

Results: Relationships between Methods



Figure 14. Relationship between traditional and holistic methods.

- Significant correlations demonstrated between sub-scores that quantify similar cmap characteristics.
- Lack of correlations between sub-socres that quantify different cmap qualities.

 Traditional and holistic methods both quantify knowledge breadth, depth, and connectedness.

Table 6. Correlations between subscores.

	NC	HH	NCL
Compre-	0.476**	0.274*	0.223
hensiveness			
Organization	-0.187	0.064	0.678**
Correctness	0.160**	-0.079	0.006
*p <u><</u> 0.05, **p <u><</u> 0.001			

Traditional and holistic cmap scoring methods show convergent validity.

Results: Category Analysis



Sustainability Categories

Figure 15. Category relevance metrics.

Undergrads most associate sustainability with environmental and resource scarcity concepts.

Grads also associate sustainability with social impacts and technology.

Complexity index (CO) significantly higher for grads (29.1) than undergrads (19.0) [F(1, 61) = 4.08, p = 0.048].

Cohen's kappa = 0.768 ("substantial" agreement).

Grads demonstrate more connections between concepts from different sustainability categories than undergrads.

Discussion: Insights for Improving Sustainability Education in CEE

- Undergrad student sustainability knowledge is valid and contains few consistencies (avg. correctness = 2.88 out of 3.00).
- Improvements could be made to aid students in recognizing interconnections between sustainability concepts (avg. organization = 1.39 out of 3.00).
- Strategies could be implemented to promote diversity of sustainability concepts, beyond those related to the environment and natural resources.
- Further horizontal and/or vertical integration of sustainability concepts and principles needed.

Discussion: Broad Implications for Cmap-Based Assessments

- Both the traditional and holistic methods can be used to reliably score cmaps by trained judges.
- Both methods are valid for measuring knowledge breadth, depth, and connectedness (convergent validity demonstrated).
- Choice of scoring method depends on application (research, classroom, etc.).
- Valid and reliable cmap-based assessments can be used to effectively guide curricula reforms.

Conclusions

- Cmaps can be reliably scored (κ_{Cohen} > 0.60) using traditional, holistic, and categorical approaches by trained judges.
- Traditional and holistic scoring procedures show convergent validity for quantifying knowledge depth, breadth, and connectedness in cmaps.
- All scoring methods can discern differences in sustainability knowledge between undergraduates and graduates.



Conclusions: Broad Implications for Cmap-Based Assessments

- Improvements are needed to help undergraduates develop a more holistic and interconnected view of sustainability.
- Concept maps can be used to guide curricula or classroom reforms if scored by trained judges.



Broader Study

Quasi-experimental approach being used to determine the impacts of integrating a sustainability module into capstone course on student sustainability knowledge

Cmap assessment of student sustainability knowledge in capstone course.

Dissemination of traditional capstone course.

Cmap assessment of student sustainability knowledge in capstone course.

Cmap assessment of student sustainability knowledge in capstone course. Development and implementation of a learning-cycle-based sustainability module in capstone course.

Cmap assessment of student sustainability knowledge in capstone course.

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