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# Assessing and Improving Student Sustainability Knowledge in Civil and Environmental Engineering at the Georgia Institute of Technology

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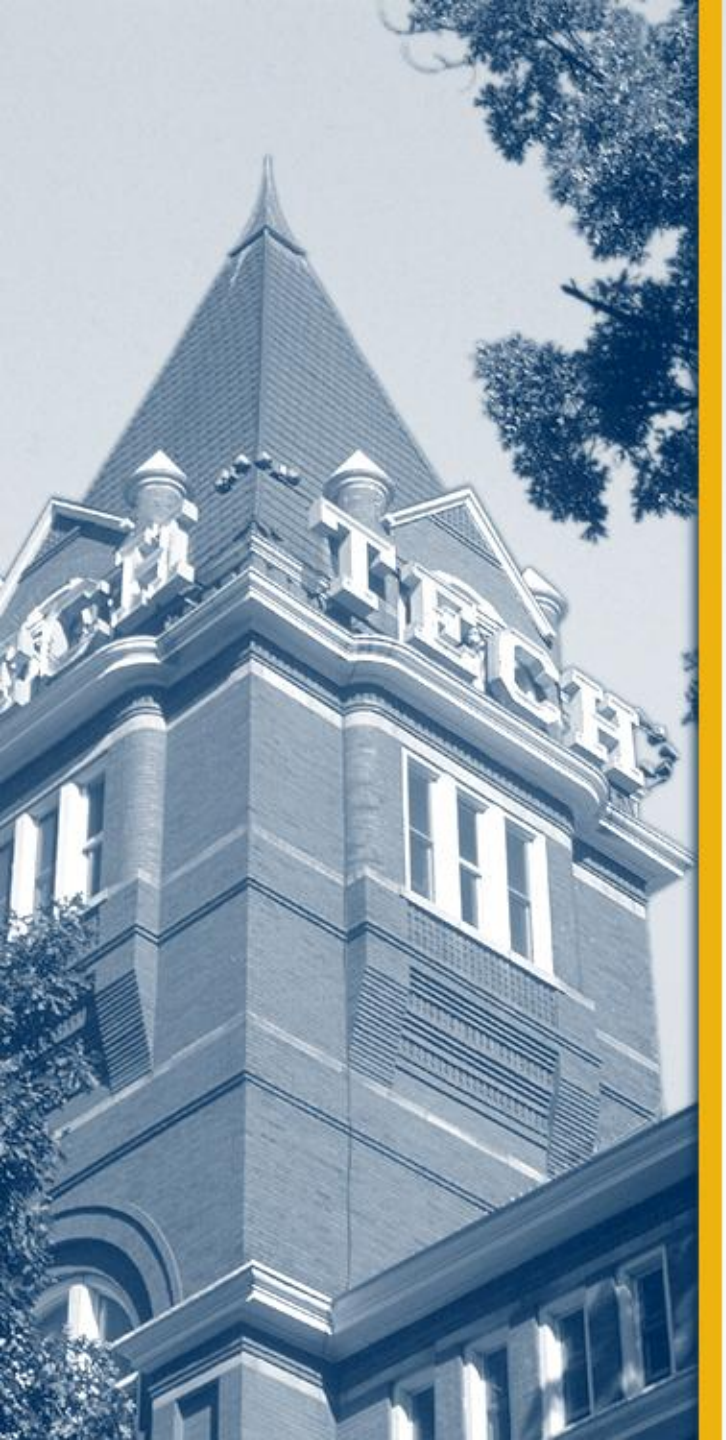



# Assessing and Improving Student Sustainability Knowledge in Civil and Environmental Engineering at Georgia Tech:

## *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.

ARTICLE

The Tragedy of the Commons

Garrett Hardin

What Shall We Maximize?

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.

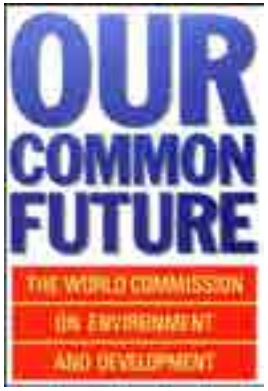



**Figure 1. *Our Common Future*, which first articulated the popular definition for sustainable development (1987).**


**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.

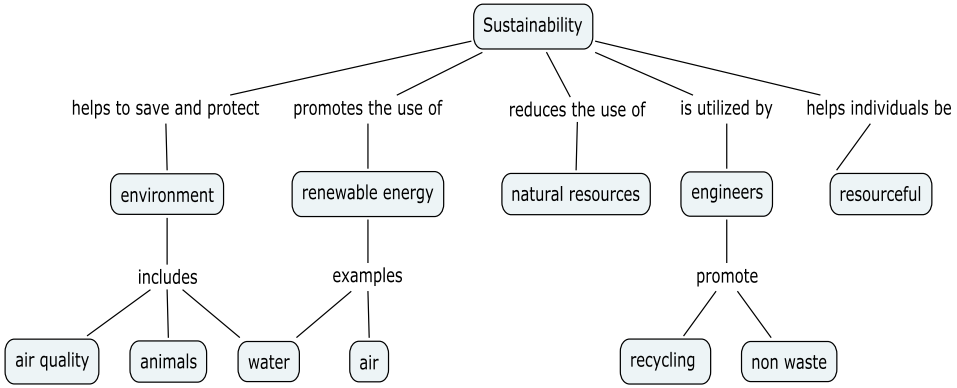



**Figure 4. Example of a simple student sustainability cmap.**

# Introduction:
## Project Overview

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

| | |
|---|---|
| Objective 1 | To determine the reliability and validity of traditional, holistic, and categorical cmap scoring methods. |
| Objective 2 | To analyze the ability of scoring approaches to discern differences in sustainability knowledge between undergraduates and graduates. |
| Objective 3 | 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

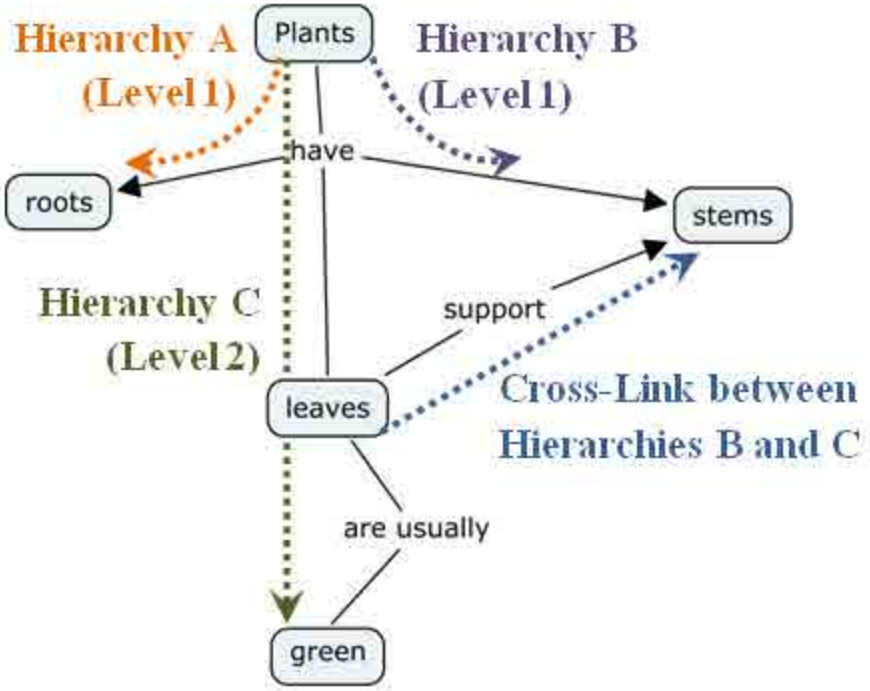



**Figure 5. Cmap components.**

*(19, 22, 27)*

# 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.

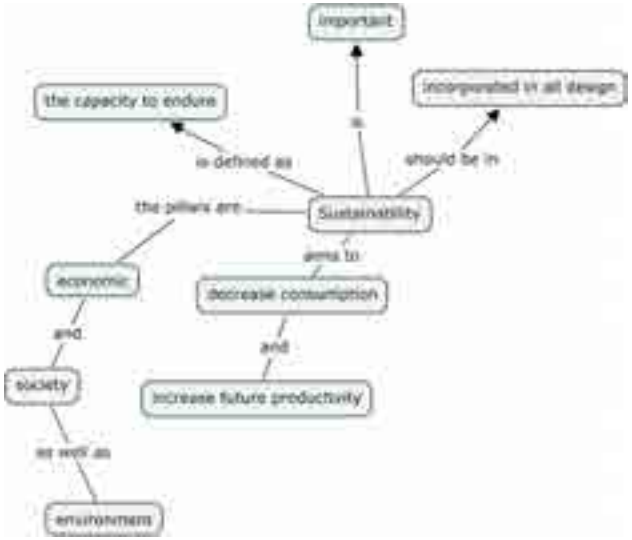



**Figure 6. Example of a simple student sustainability cmap.**

*(23, 28-31)*

# Concept Maps:
## Use as Assessment Tools

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

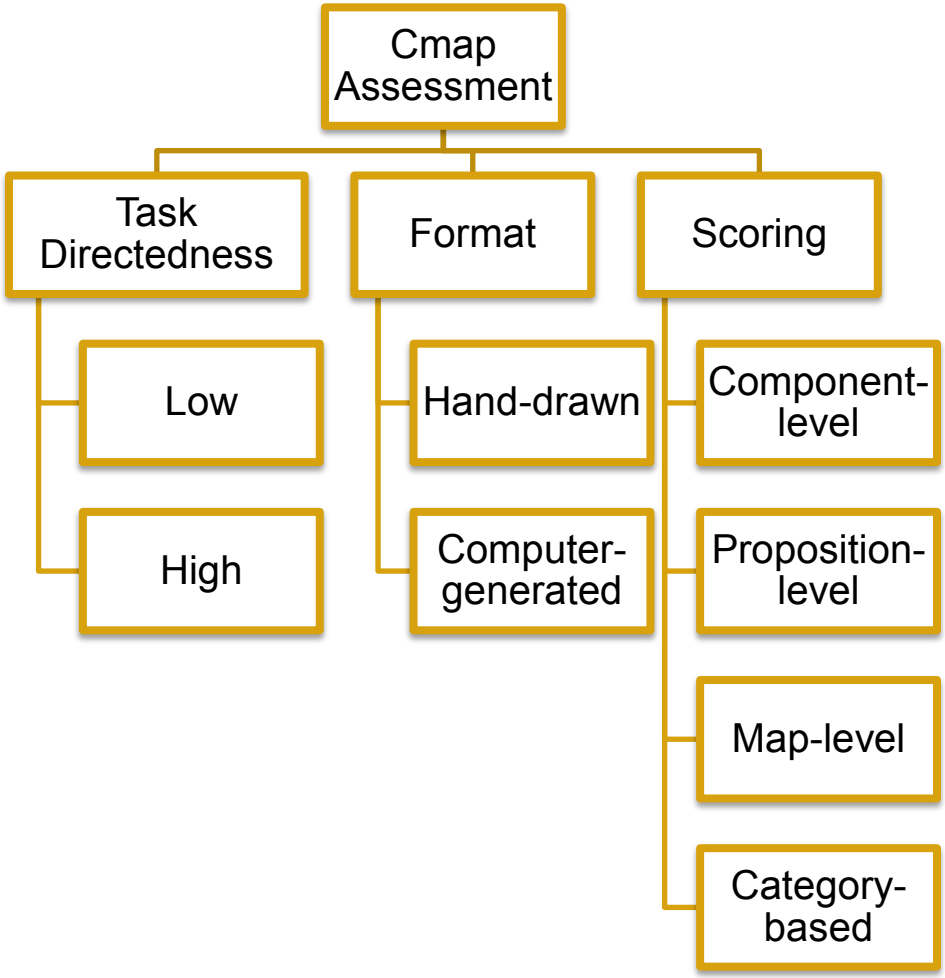



**Figure 7. Components of a cmap assessment.**

# 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.

**Table 1. Components of traditional cmap score.**

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

*(21, 35-41)*

# 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.

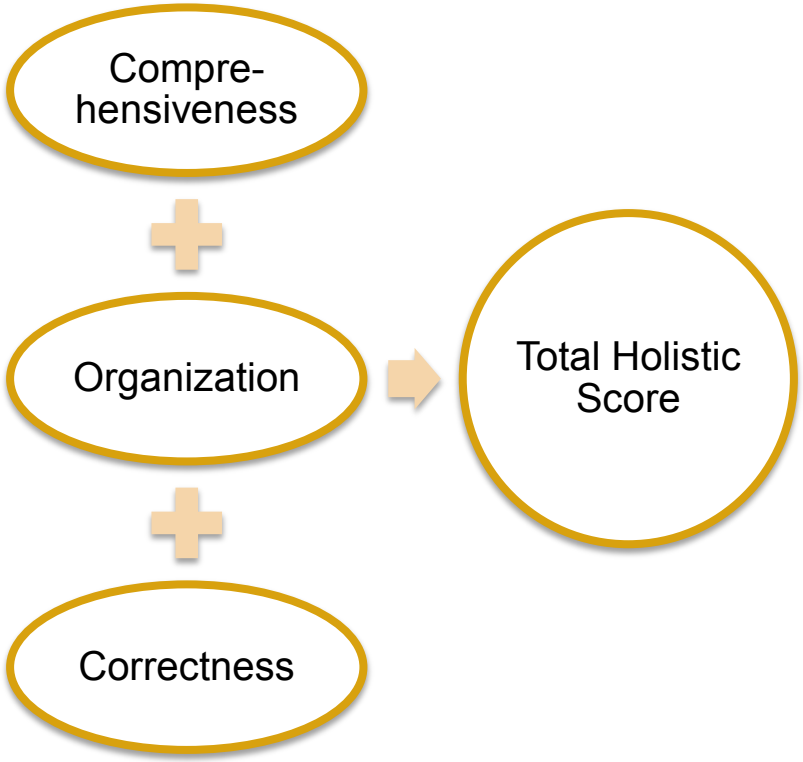



**Figure 8. Calculation of total holistic score.**

# 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.
- Segalàs et al.[42] investigated the effectiveness of six sustainability courses by comparing student cmaps before and after course delivery[42].
- 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].

*(19, 23, 35, 42-46)*

# 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?"

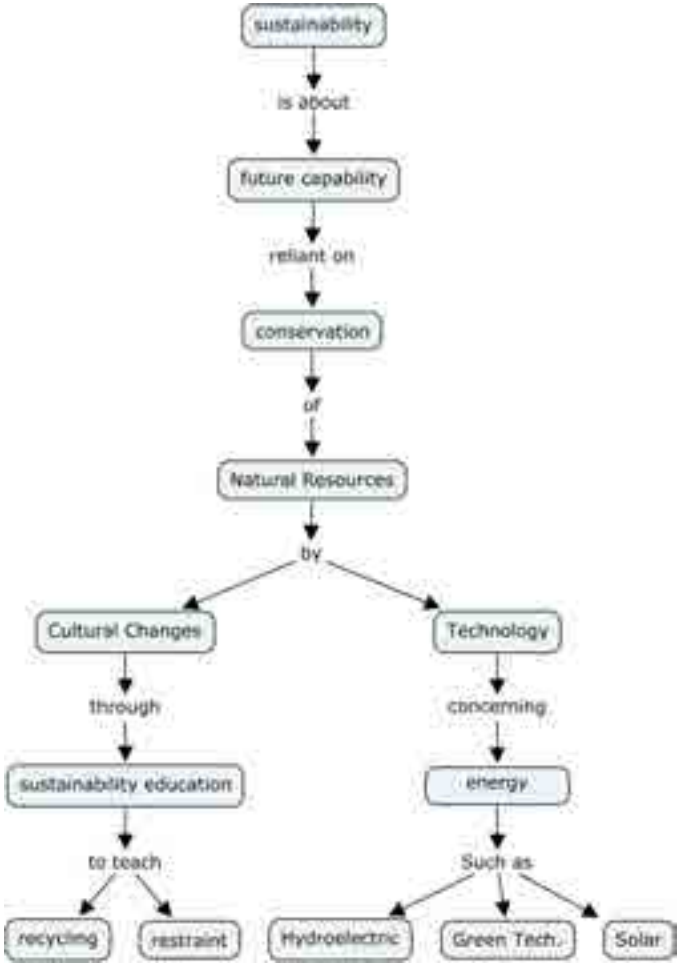



**Figure 10. Sample student sustainability cmap.**

# 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 |
| GPA[a] | | |
| 3.5 ≤ GPA ≤ 4.0 | 35.4 | 100 |
| 3.0 ≤ GPA < 3.5 | 31.3 | 0 |
| 2.5 ≤ GPA < 3.0 | 18.8 | 0 |
| 2.0 ≤ 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.**

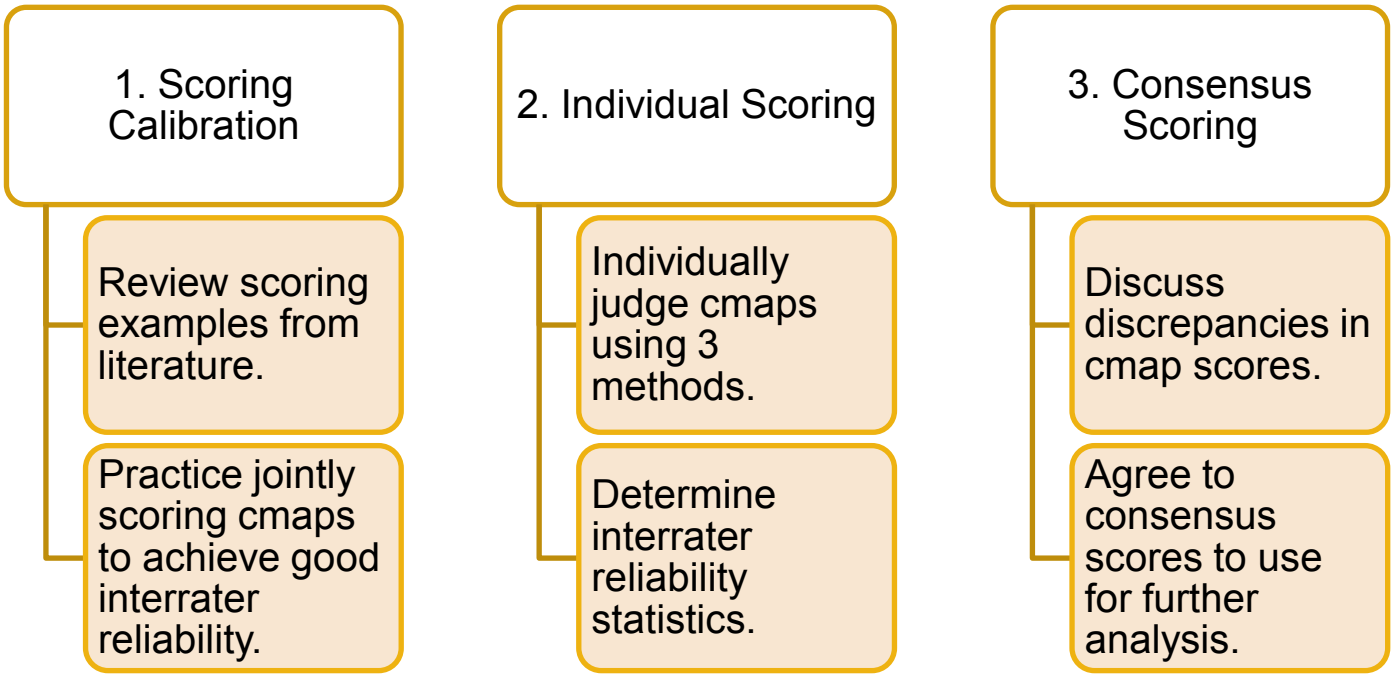



**Figure 11. Methodology used to score cmaps.**

# 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].

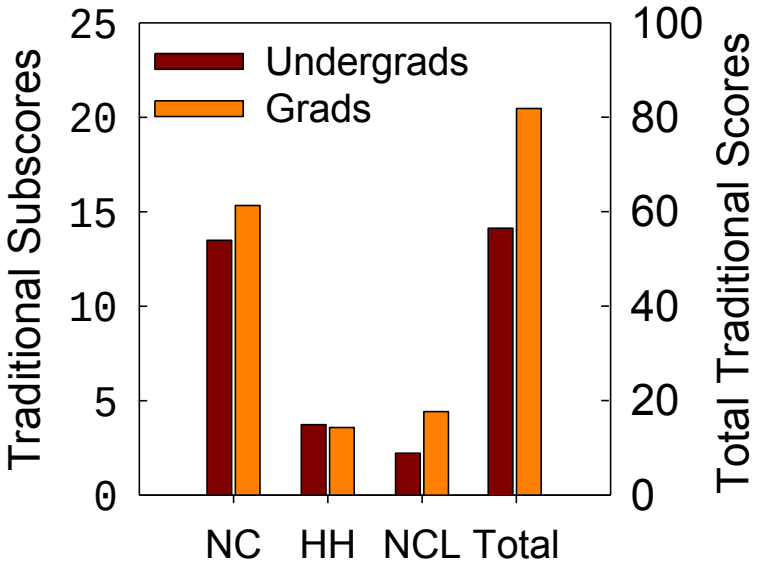



**Figure 12. Traditional cmap scores.**

**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 ($\kappa \geq 0.80$).
- Krippendorff's alpha within "adequately acceptable" range ($\alpha \geq 0.80$).
- Cronbach's alpha within "excellent" range ($\alpha \geq 0.90$).

# 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].

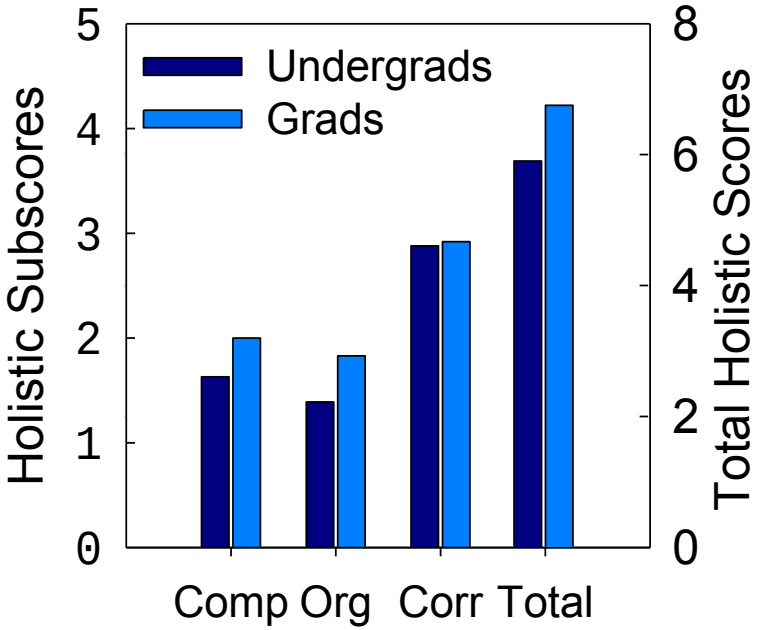



**Figure 13. Holistic cmap scores.**

**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 ($\kappa \geq 0.80$).
- Most Krippendorff's alpha within "adequately acceptable" range ($\alpha \geq 0.67$).
- Cronbach's alpha within "good" range ($\alpha \geq 0.80$).

# Results:
# Relationships between Methods

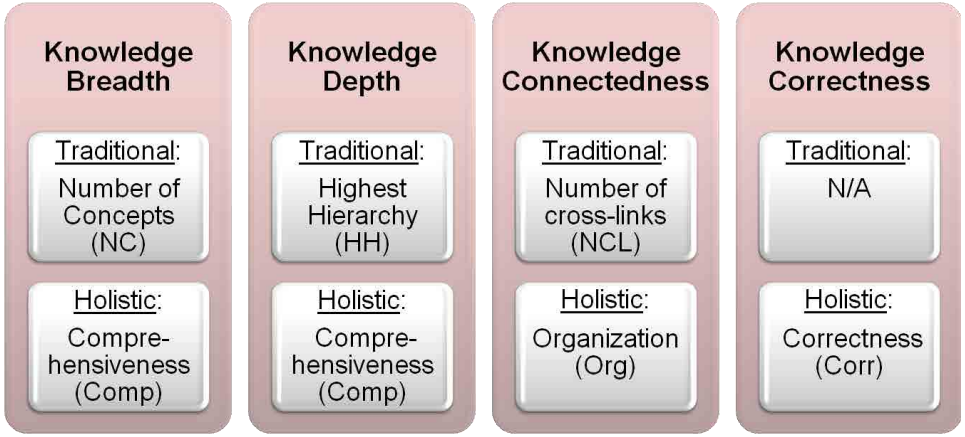



**Figure 14. Relationship between traditional and holistic methods.**

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

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

**Table 6. Correlations between subscores.**

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

*p ≤ 0.05, **p ≤ 0.001

**Traditional and holistic cmap scoring methods show convergent validity.**

# Results:
## Category Analysis

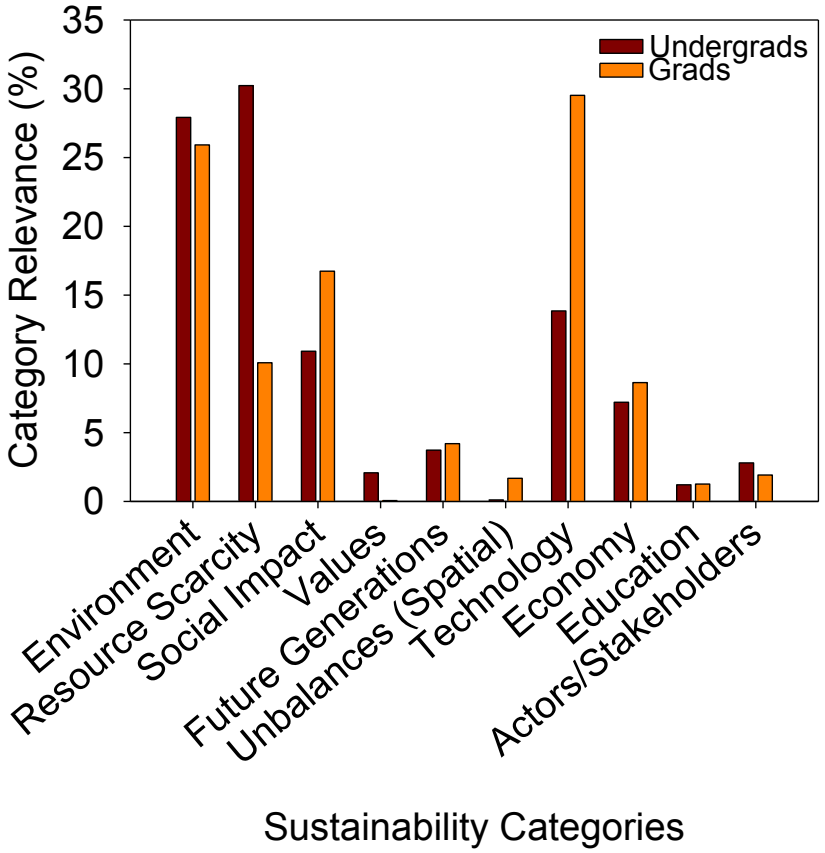



**Figure 15. Category relevance metrics.**

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

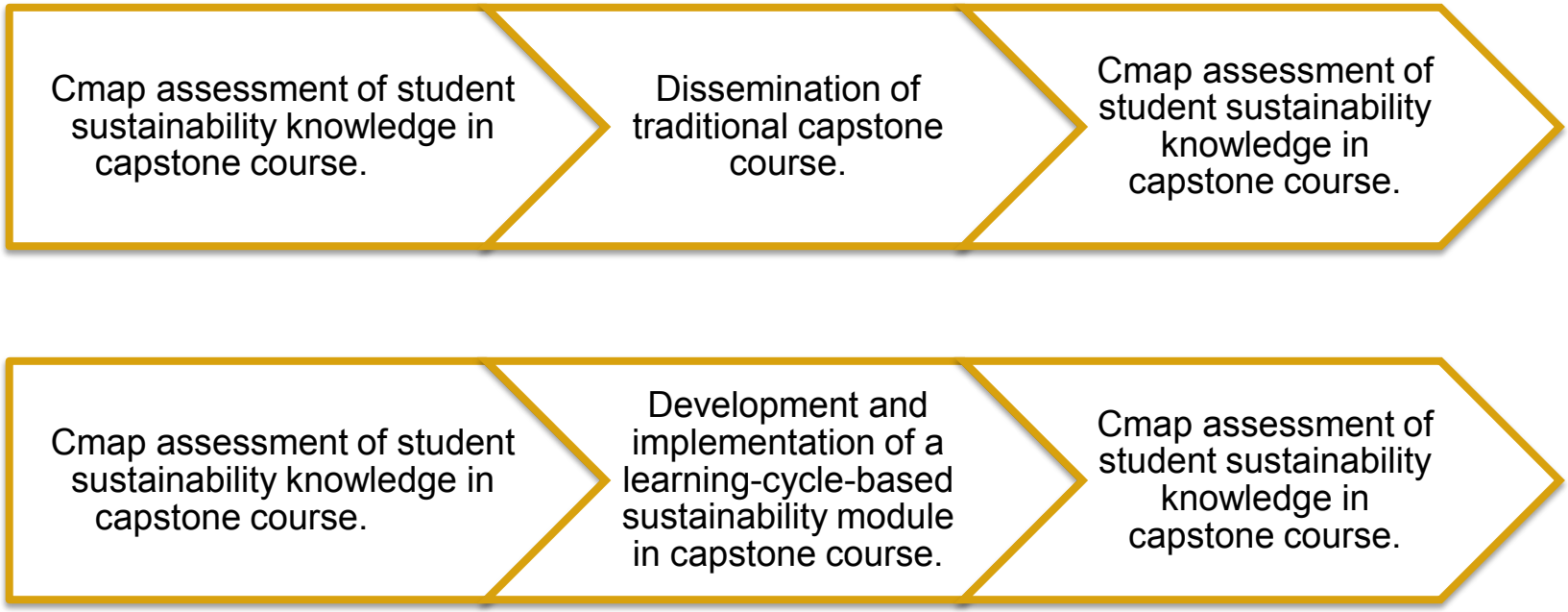
- Cmaps can be reliably scored ($\kappa_{Cohen} > 0.60$) using traditional, holistic, and categorical approaches by trained judges.
- Traditional and holistic scoring procedures show convergent validity for quantifying knowledge depth, breadth, and connectedness in cmaps.
- All scoring methods can discern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



# References


1. *Our Common Future*; United Nations World Commission on Environment and Development (UNWCED): 1987.
2. Meadows, D. H.; Meadows, D. L.; Randers, J.; Behrens, W. H., *The Limits to Growth*. Universe Books, Inc.: New York, NY, 1972.
3. *Johannesburg Declaration*; United Nations World Summit on Sustainable Development (UNWSSD): Johannesburg, South Africa, 2002. Accessed Available at:
4. Harris, J. M. *Basic principles of sustainable development*; Tufts University: Global Development and Environment Institute: Medford, MA, 2000. Working Paper 00-04. Accessed Working Paper 00-04. Available at:
5. Holmberg, J.; Sandbrook, R., Sustainable Development: What Is to be Done? In *Making Development Sustainable: Redefining Institutions, Policy, and Economics*, Holmberg, J., Ed. International Institute for Environment and Development: Washington, D.C., 1992; pp 19-38.
6. Diesendorf, M., Sustainability and Sustainable Development. In *Sustainability: The Corporate Challenge of the 21st Century*, Dunphy, D.; Benveniste, J.; Griffiths, A.; Sulton, P., Eds. Allen & Unwin Academic: Crows Nest, NSW, 1999.
7. Kates, R. W.; Clark, W. C.; Corell, R.; Hall, J. M.; Jaeger, C. C.; Lowe, I.; McCarthy, J. J.; Schellnhuber, H. J.; Bolin, B.; Dickson, N. M.; Faucheux, S.; Gallopin, G. C.; Grabler, A.; Huntley, B.; Jager, J.; Jodha, N. S.; Kasperson, R. E.; Mabogunje, A.; Matson, P.; Mooney, H.; Moore, B.; O'Riordan, T.; Svedin, U., Sustainability science. *Science* **2001**, *292*, (5517), 641-642.
8. Lovelock, J., *The Revenge of Gaia*. Penguin Group: London, England, 2007.
9. Lozano, R., Diffusion of sustainable development in universities' curricula: an empirical example from Cardiff University. *Journal of Cleaner Production* **2010**, *18*, (7), 637-644.
10. Cortese, A. D., The critical role of higher education in creating a sustainable future. *Planning for Higher Education* **2003**, *31*, (3), 15-22.

# References


11. Davidson, C. I.; Matthews, H. S.; Hendrickson, C. T.; Bridges, M. W.; Allenby, B. R.; Crittenden, J. C.; Chen, Y.; Williams, E.; Allen, D. T.; Murphy, C. F.; Austin, S., Viewpoint: Adding sustainability to the engineer's toolbox: A challenge for engineering educators. *Environmental Science & Technology* **2007**, *41*, (14), 4847-4849.
12. Thompson, G., Status and prospects of sustainable engineering education in some American universities. In *Engineering Education in Sustainable Development*, Delft University of Technology, Netherlands, 2002.
13. Kelly, B., Sustainability in engineering education and ethics. *Connexions* 2008.
14. Lozano, R., Incorporation and institutionalization of SD into universities: breaking through barriers to change. *Journal of Cleaner Production* **2006**, *14*, (9-11), 787-796.
15. Ceulemans, K.; De Prins, M., Teacher's manual and method for SD integration in curricula. *Journal of Cleaner Production* **2010**, *18*, (7), 645-651.
16. Peet, D. J.; Mulder, K. F., Integrating SD into engineering courses at the Delft University of Technology. *International Journal of Sustainability in Higher Education* **2004**, *5*, (3), 278-288.
17. UBC Sustainability Courses. University of British Columbia. Accessed 2011 June 8. <http://www.sustain.ubc.ca/teaching-learning/curriculum/courses>.
18. Goldsmith, T. E.; Johnson, P. J., A Structural Assessment of Classroom Learning. In *Pathfinder Associative Networks: Studies in Knowledge Organization*, Schvaneveldt, R. W., Ed. Ablex: Norwood, NJ.
19. McClure, J.; Sonak, B.; Suen, H. K., Concept map assessment of classroom learning: reliability, validity, and logistical practicality. *Journal of Research in Science Teaching* **1999**, *36*, (4), 475-492.
20. Angelo, T.; Cross, K. P., *Classroom Assessment Techniques: A Handbook for College Teachers*. 2nd ed.; Jossey Bass: San Francisco, CA, 1993.
21. Besterfield-Sacre, M.; Gerchak, J.; Lyons, M. R.; Shuman, L. J.; Wolfe, H., Scoring concept maps: An integrated rubric for assessing engineering education. *Journal of Engineering Education* **2004**, *93*, (2), 105-115.
22. Novak, J. D.; Canas, A. J. *The Theory Underlying Concept Maps and How to Construct Them*; Institute for Human and Machine Cognition: 2006. Accessed June 9, 2011. Available at: <http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMapsHQ.pdf>.

# References


23. Ruiz-Primo, M. A.; Shavelson, R. J., Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching* **1996**, *33*, (6), 569-600.
24. Wilson, J. M., The predictive validity of concept mapping: Relationships to measure achievement. In *Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Misconceptions Trust: Ithica, NY, 1993.
25. Liu, X.; Hinchey, M., The validity and reliability of concept mapping as an alternative science assessment In *Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Misconceptions Trust: Ithica, NY, 1993.
26. Lomask, M. S.; Baron, J. B.; Grieg, J., Assessing conceptual understanding in science through the use of two- and three-dimensional concept maps. In *Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, Misconceptions Trust: Ithica, NY, 1993.
27. Turns, J.; Atman, C.; Adams, R., Concept maps for engineering education: a cognitively motivated tool supporting varied assessment functions. *IEEE Transactions on Education* **2000**, *43*, (2).
28. Tulving, E., Episodic and Semantic Memory. In *Organization of Memory*, Tulving, E.; Donaldson, W., Eds. Academic Press: Oxford, England, 1972.
29. Collins, A. M.; Quillian, M. R., Facilitating retrieval from semantic memory: The effect of repeating part of an inference. *Acta Psychologica* **1970**, *33*, 304-314.
30. Collins, A. M.; Loftus, E. F., A spreading-activation theory of semantic processing. *Psychological Review* **1975**, *82*, (6), 407-428.
31. Ruiz-Primo, A., On the use of concept maps as an assessment tool in science: What we have learned so far *Revista Electrónica de Investigación Educativa* **2000**, *2*, (1), 29-53.
32. Prince, M. J.; Felder, R. M., Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education* **2006**, *95*, (2), 123-138.
33. Bhattacharya, K.; Han, S., Piaget and cognitive development. In *Emerging perspectives on learning, teaching, and technology*, Orey, M., Ed. University of Georgia: Athens, GA, 2001.

# References


34. Novak, J. D.; Canas, A. J., Theoretical origins of concept maps, how to construct them, and uses in education. *Reflecting Education* **2007**, *3*, (1), 29-42.
35. Novak, J. D., *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations*. Lawrence Erlbaum Associates: Mahwah, NJ, 1998.
36. Cañas, A. J.; Hill, G.; Carff, R.; Suri, N.; Lott, J.; Gomez, G.; Eskridge, T. C.; Arroyo, R. C. In *CmapTools: A knowledge modeling and sharing environment*, Second International Conference on Concept Mapping, Pamplona, Spain, 2004; Cañas, A. J.; Novak, J. D.; Gonzalez, F. M., Eds. Pamplona, Spain, 2004.
37. Bayram, S. The Effectiveness of Concept and Software Mapping for Representing Student Data and Process Schema in Science. Masters, University of Pittsburgh, Pittsburgh, PA, 1995.
38. Markham, K. M.; Mintzes, J. J.; Jones, M. G., The concept map as a research and evaluation tool: Further evidence of validity. *Journal of Research in Science Teaching* **1994**, *31*, (1), 91-101.
39. Ruiz-Primo, A. In *Examining concept maps as an assessment tool*, Concept Maps: Theory, Methodology, Technology, Pamplona, Spain, 2004; Canas, A. J.; Novak, J. D.; Gonzalez, F. M., Eds. Pamplona, Spain, 2004.
40. Ruiz-Primo, A.; Shavelson, R. J.; Li, M.; Schultz, S. E., On the validity of cognitive interpretations of scores from alternative concept-mapping techniques. *Educational Assessment* **2001**, *7*, (2), 99-141.
41. Borrego, M.; Newswander, C. B.; McNair, L. D.; McGinnis, S.; Paretti, M. C., Using concept maps to assess interdisciplinary integration of green engineering knowledge. *Advances in Engineering Education* **2009**, *1*, (3), 1-26.
42. Segalàs, J.; Ferrer-Balas, D.; Mulder, K. F., Conceptual maps: measuring learning processes of engineering students concerning sustainable development. *European Journal of Engineering Education* **2008**, *33*, (3), 297 - 306.
43. Segalàs, J.; Ferrer-Balas, D.; Mulder, K. F., What do engineering students learn in sustainability courses? The effect of the pedagogical approach. *Journal of Cleaner Production* **2010**, *18*, (3), 275-284.
44. Valdes-Vasquez, M.; Klotz, L., Incorporating the social dimension of sustainability into civil engineering education. *Journal of Professional Issues in Engineering Education & Practice* **2010**, *In press*.

# References


45. Valdes Vasquez, R.; Klotz, L., Considering social dimensions of sustainability during construction project planning and design. *The International Journal of Environmental, Cultural, Economic and Social Sustainability* **2010**, *6*, (6), 167-180.
46. Valdes-Vasquez, M.; Klotz, L., Incorporating the social dimension of sustainability into civil engineering education. *Journal of Professional Issues in Engineering Education & Practice* **2010**.