Concept Maps as Teaching, Learning, and Research Tools

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***Abstract* – Concept maps are graphical tools for organizing knowledge that can be used to assess students' conceptual knowledge in a particular domain. Construction of concept maps is completed by enclosing concepts related to a central topic in boxes and using connecting lines, as well as linking phrases, to depict relationships between concepts. Since concept maps mimic the structure of internal semantic networks, student-generated constructs may be used to infer a student's understanding of a particular domain. To quantify student knowledge as captured in a concept map, several scoring methods are available that range from component-level to map-level analysis. Use of concept maps in engineering education has been limited in part due to difficulty in administration and scoring of student constructs. This workshop is designed to aid educators and researchers in effective and efficient use of concept maps in engineering education, with emphasis on development, application, and scoring of concept mapping assessments for first-year engineering contexts.**

Index Terms – Assessment tools, Concept maps, Conceptual knowledge

INTRODUCTION

To meet society's needs in the context of complex design constraints, engineers must possess a deep conceptual understanding of engineering fundamentals so that they can critically analyze new problems and solutions [1]. Conceptual knowledge goes beyond just knowing facts and concepts. While conceptual knowledge certainly includes general knowledge about facts, it also encompasses how those facts are organized [2-4]. Rittle-Johnson [3] emphasized that interrelations between concepts are important, while Starr [5] stated that conceptual understanding must be "deep" and "rich with connections" (p. 408). Indeed, Bransford, Brown, and Cocking [6] stated that experts structure knowledge around central ideas, while Alexander and Murphy [7] argued that "the subject-matter knowledge of competent learners is coherently organized around key domain concepts and principles" (p. 566). Conceptual knowledge is thus factual, structured, and interrelated.

Due to the importance of conceptual knowledge in the development of problem-solving abilities, many engineering educators are striving to apply innovative educational interventions to encourage deep learning rather than rote memorization of facts and solution procedures [8]. Consequently, assessments for evaluating the impact of innovative educational practices on conceptual knowledge are greatly needed. Traditional assessment instruments, such as multiple choice or standardized tests, are objective [9], although they inherently restrict student responses and provide little insight into knowledge structure [10]. Open-ended assessment methods, such as essays and presentations, are usual alternatives to objective tests that disclose more about knowledge structure [10], organization [9], and creativity [11]. However, student inability to produce acceptable artifacts (for example, reports or posters) may be mistaken for lack of knowledge in the domain [10]. Due to the shortcomings of popular assessments, more innovative tools, such as concept maps, have been suggested for more accurately capturing conceptual knowledge in a particular domain [12].

CONCEPT MAPS AS ASSESSMENT TOOLS

Concept maps can be used to capture the structure and content of student knowledge in a given domain. Use of concept maps as assessment tools has been suggested for characterizing student understanding in a variety of engineering disciplines, including civil engineering [13], industrial engineering [12], bioengineering [14], and mechanical engineering [15].

I. Structure and Function

Concept maps are graphical tools for organizing knowledge (Figure I). Construction of a concept map is completed by enclosing concepts related to a central topic in boxes and using connecting lines, as well as linking phrases, to depict relationships between concepts [16]. The basic unit of a concept map is a proposition, which includes two concepts joined by a descriptive linking line. Propositions that include the concept map topic define the map hierarchies, and the level of hierarchy is defined by the number of concepts in the hierarchy. Cross-links, which are important for depicting connectedness, are descriptive linking lines that create propositions by joining two concepts from different map hierarchies [17].

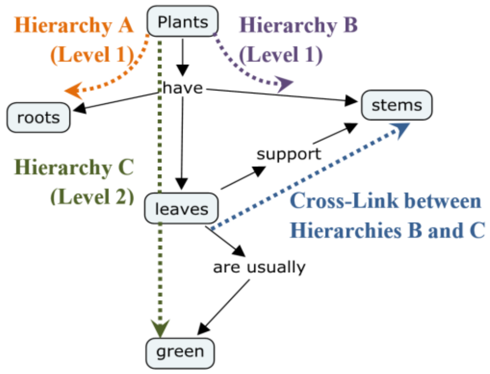

FIGURE 1
CONCEPT MAP HIERARCHIES AND CROSS-LINKS [16].

II. Theoretical Bases

Use of concept maps is supported by cognitive psychological research in the area of semantic memory theory. Semantic memory refers to an organized database of concept-based knowledge, such as meanings, understandings, and images [18]. Semantic memory theory posits that knowledge networks are formed by creating directed links between related concepts. Some researchers have proposed that networks are structured hierarchically with broad concept categories being divided into more specific sub-categories, while other researchers have rejected this assumption [19]. Nevertheless, interconnectedness within the structure is an important network characteristic, since it increases one's ability to access concepts [20] and is a key feature that differentiates expert and novice knowledge frameworks [19]. Since concept maps mimic the structure of internal semantic networks, student-generated constructs may be used to infer a student's domain understanding.

III. Use as Assessment Tools

One significant challenge in using concept maps as assessment tools is identification and application of a robust scoring method [e.g., 12]. Such methods are required for comparing student performance, both between populations and over time. In the literature, researchers have proposed several methods to evaluate concept maps, including the traditional, holistic, and categorical scoring methods.

The traditional scoring method [e.g., 12] involves quantifying the number of components in each concept map (Table I). The number of concepts (NC) included in the maps is counted to serve as an indicator of knowledge breadth. Next, hierarchies, which are defined by propositions that include the concept map topic, are analyzed. Concepts in each hierarchy are counted and the maximum number of concepts in a hierarchy (i.e., the highest hierarchy; HH) is an indicator of knowledge depth. Finally, the number of cross-links (NCL), which are links between concepts from different hierarchies, are used as a measure of knowledge connectedness. The total traditional score can be calculated by awarding 1 point for each concept, 5 points for each level of hierarchy, and 10 points for each cross-link [17].

Instead of analyzing individual components, the concept map as a whole can be evaluated. For instance, Besterfield-Sacre et al. [12] developed the holistic scoring rubric in which judges use a three-point scale to rate the comprehensiveness, organization, and correctness of concept maps. In analyzing comprehensiveness, judges consider the variety of topics (knowledge breadth) and also how extensively topics are covered (knowledge depth). Scoring the organizational dimension requires evaluation of the concept map structure, including the links within and between hierarchies (knowledge connectedness). Unlike the traditional method, the holistic method includes a correctness sub-score, which characterizes the overall appropriateness of propositions and concept placements. Finally, the total concept map score is computed by simply adding the three sub-scores (Table I).

TABLE I
TRADITIONAL AND HOLISTIC SCORING METHODS [12, 16-17].

Method	Equation
Traditional	Total = (NC-NCL)[c] + (HH)*5 + (NCL)*10
Holistic	Total = Comp. + Org. + Corr.

[a]NC = number of concepts; HH = highest hierarchy; NCL = number of cross links.
[b]Comp. = comprehensiveness; Org. = organization; Corr. = correctness.
[c]Formula ensures that cross-linked concepts are not double-counted.

The categorical scoring method was developed specifically for sustainability-related concept maps, but it can be adapted for any domain. To apply the categorical scoring method, judges first categorize each concept in a concept map according to appropriate categories. Next, judges count the number of inter-links, or connections between concepts from different categories. As per Watson, Pelkey, Noyes, and Rodgers [17] and Segalàs, Ferrer-Balas, and Mulder [21], the category distribution can be used to analyze the extent to which a student associates a specific category with the central topic. The student-specific complexity index can be calculated to characterize the overall coverage of and connectedness between the categories (Table II).

TABLE II
SUMMARY OF CATEGORICAL SCORING METHOD [17, 21].

Metric	Equation[a]
Category Distribution	$CD_{i,j} = NC_{i,j} \Big/ \sum_{i=1}^{N_{Ca}} NC_{i,j}$
Complexity Index	$CO_j = NC_j \left(NIL_j / N_{Ca} \right)$

[a]$CD_{i,j}$ = concept distribution for category *i*, $NC_{i,j}$ = number of concepts included in category *i*, N_{Ca} = number of categories, CO_j = student-specific complexity index, NC_j = total number of concepts for student *j*, NIL_j = number of inter-links for student *j*.

WORKSHOP DESCRIPTION

Concept maps have been used in educational settings as a learning strategy, an instructional method, a curriculum planning guide, and an assessment tool. Their adoption as assessment tools, however, has been limited by difficulty in administration and scoring of student constructs. Consequently, this workshop is designed to aid educators and researchers in effective and efficient use of concept maps in engineering education. After completing this workshop, participants will be able to:

- Identify potential uses for concept maps in their teaching and research endeavors, especially related to first-year engineering education.
- Use CmapTools, a free computer software, for creating concept maps.
- Summarize application of multiple concept map scoring methods.
- Construct and score concept maps using the traditional scoring method.
- Access the use of an automated computer program for scoring concept maps using the traditional method.

The 90-minute workshop will be highly-interactive. Participants, through collaboration with peers, will develop a concept mapping assessment for use in their own teaching and/or research contexts. It is recommended that participants bring their laptops to practice use of concept mapping software and the automated scoring program.

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