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Knowledge Structures and the Vocabulary of Engineering Novices

Abstract: This paper describes a study of the language used by undergraduate engineering students engaged in a civil engineering laboratory. Learner's concepts and relationships in the area of *soil consolidation* were elicited in order to provide an understanding of the structural knowledge of novices and compare it with the knowledge structures of a human expert and a thesaurus tool. Concept maps and pathfinder networks were used to visualize and analyze the resultant knowledge structures of novice learners, expert, and tool. Results show that there is little similarity between the knowledge structures of the novice, the expert, and the tool.

1. Introduction:

A small study is described which investigated the vocabulary as reflected in the knowledge structures of novices. The research was conducted in order to understand how knowledge organization tools may be designed to meet the needs of novices in the GROW digital library. GROW is the Geo-technical, Rock, and Water digital library, the first step in the establishment of a National Civil Engineering Resources Library (NCERL). Digital libraries are complex entities that have many components: besides the collections of individual resources and the interface to these resources, they have organization, labeling, navigation and searching systems. Controlled vocabularies and thesauri are often the invisible components. This study is based on the premise that the controlled vocabulary influences the above mentioned related components in the digital library. We felt that it was important to understand the knowledge structures of a primary group of user, the novice - the student learner – who is new to the domain. A great deal of research has been done about how people learn and how people use information, but fewer studies link science knowledge structures, vocabulary, and language use.

2. Background:

Science knowledge is often divided into two types: declarative and procedural. However, there is also another type, namely structural knowledge that mediates between these two types, by transforming declarative into procedural knowledge. Structural knowledge reflects the organization and interrelationships of concepts in a domain. There is some evidence, from schema theory, that structural knowledge has an important impact on the problem-solving abilities of learners; the knowledge organization explanation for learning suggests that experts have a larger range of chunks that are better organized (Chi, Glaser, & Feltovich, 1981). Structural knowledge is considered to be an important part of cognitive processing because it affects the learners' ability to use what they have learned.

The structural knowledge of learners and experts can be represented and analyzed using many mapping methods. Concept maps and pathfinder networks (Schvaneveldt, 1990) are used in this study. A concept map represents the learner's knowledge as concepts and relationships through nodes and links with the links indicating relationships through the use of a linking phrase; a pathfinder network also describes the interrelationships of concepts within a content domain as found in the mind of the learner; i.e., the state of the structural knowledge about a concept at any given moment in time.

3. Methods:

Subjects: Novices and experts from a civil engineering, geo-technical laboratory class, at a major southwestern university in the United States were solicited for voluntary participation.

Course: The Geo-technical laboratory is a laboratory course that must be taken either with a three-unit Soils course or soon after it. There are approximately ten labs that must be completed over the course of the 16-week semester for a course value of one credit hour. The lab manual used was *Engineering properties of soils and their measurements*, Joseph E. Bowles, 4th edition, New York, McGraw-Hill.

Laboratories: From the list of ten laboratories, the experiment on primary consolidation titled "Consolidation," was selected for further study. There are two delivery formats available: as a virtual test and as a physical test. Participants in the study were required to complete both formats of the test. The consolidation experiment is a laboratory that is used to teach about the settlement of soils. It is a common, physical, laboratory test in undergraduate curricula in civil engineering. This test is very time-consuming and often lasts anywhere from two to seven days. Unfortunately, due to time constraints students often only have time to actually carry out a three-hour part of the test. Virtual laboratories are gaining in popularity in engineering education because of their advantages. Among these, often cited ones are less cost than maintaining a physical lab and 24/7 access to learners. There are additional advantages that may be lab-specific. For example, because sample preparation requires at least three hours, in physical consolidation tests sample preparation is generally not done by students but rather by teaching assistants, instructors or technicians. In the virtual consolidation test, all the procedures – including sample preparation – are simulated in a 3D laboratory environment and can be performed by students.

Protocol and Data Collection: Novices first performed a virtual and a physical laboratory on the soils concept, *primary consolidation.* After completion of the labs, they engaged in three interviews with the research team of the investigator and the graduate research assistant. The first interview was conducted after completion of the virtual laboratory and the second was conducted after the physical lab experiment was done. At both these interviews students were asked to list the concepts and relationships in primary consolidation. The statements students made were transcribed onto cards. In the follow-up, third and final, interview, students were provided with the 201 unique statements on cards and asked to sort them into categories. The basic idea was to get statements sorted and labeled into concepts and relationships. Additionally, they were questioned about concept relatedness with a list of concepts that included terms from the tool. The expert participated in three interviews also. In the first, the interview elicited the key concepts and relationships for primary consolidation. In the second, the expert performed the card sort using the 201 cards of the students. In the third, the expert review and rated.

Data Analysis: Concept maps were generated of the statements made by each student after each interview; thus, for each student there are three concept maps, one representing the state of their knowledge at the end of the virtual lab, one representing their knowledge at the end of the physical laboratory, and the third representing the categories that resulted from the card sort, resulting in a total of 30 concept maps. Additionally, pathfinder networks were generated for each student's rating of relatedness among the statement and categories. Similarly, concept maps and pathfinder networks were also drawn for the expert's three interviews. Elsevier's Engineering Index Thesaurus was used to generate the concept map and pathfinder network for the primary term soil consolidation and all relationships. Only the results of the comparison of the concept maps and networks which represent category labels (concepts and relationships identified in final interviews), among novices, expert, and tool is described here. Examples of earlier analysis can be found in presentations by Coleman on [GROW].

4. Results:

First, we present general data about participants. Then, we present the major findings that are related to 1) the nature of conceptual maps, and 2) similarities and differences between the novice, expert, and tool.

Characteristics of novices and expert: Novices were 10 undergraduate students (civil engineering majors). They ranged from 20.1 –36.2 years of age. There were two females and eight males and their ethnicity was: one African-american, two latinos / latinas, and seven Caucasians. The expert was the lab instructor, a doctoral student in Civil Engineering, with considerable international service (10 years in Europe, Asia, and US) as a practicing engineer in geo-technics.

Nature of conceptual maps: Figures 1 through 4 depict four concept maps that reflect categories of two novices, the expert, and the tool. These two novice maps vary greatly from the simple to the complex (Figure 1 and Figure 2 below). The map in Figure 1 is a simple schematic that divides the knowledge into three areas: theory, process (which is practice) and calculations (methods).

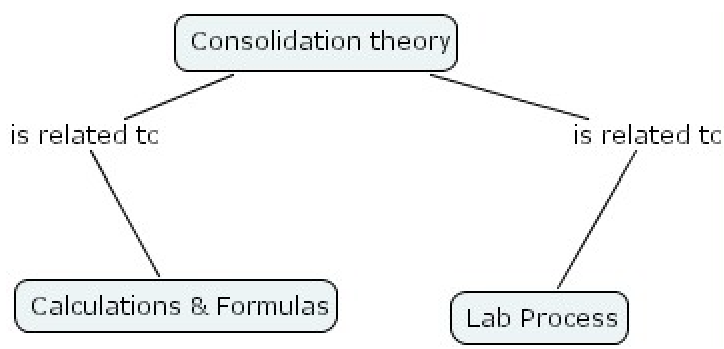

Figure 1: Simple concept map of student 1

The concept maps of the two novices and the expert show a preoccupation with learning/teaching, the organizational framework for the concept); structural knowledge about the concept (subject) is clearly interlinked in their minds to learning perspectives, such as how best to do it. The calculations and formulas category is one that was represented in all novice concept maps.

The more complex Figure 2 show that the student 3 had more categories, some of which are redundant, but illustrate the underlying organization schema. Fig. 3, the expert sees the subject in terms of the lab experiment to be done: consolidation is a load test. The expert eliminated many of the statements into the category "general statements."

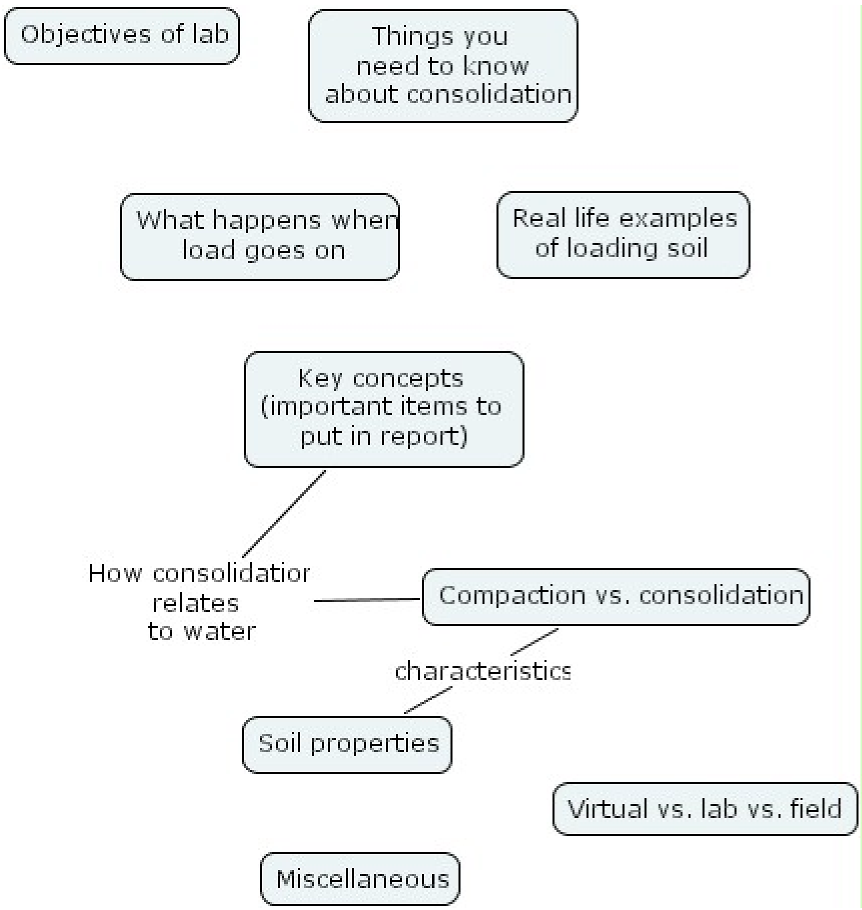

Figure 2: Complex concept map of student 3

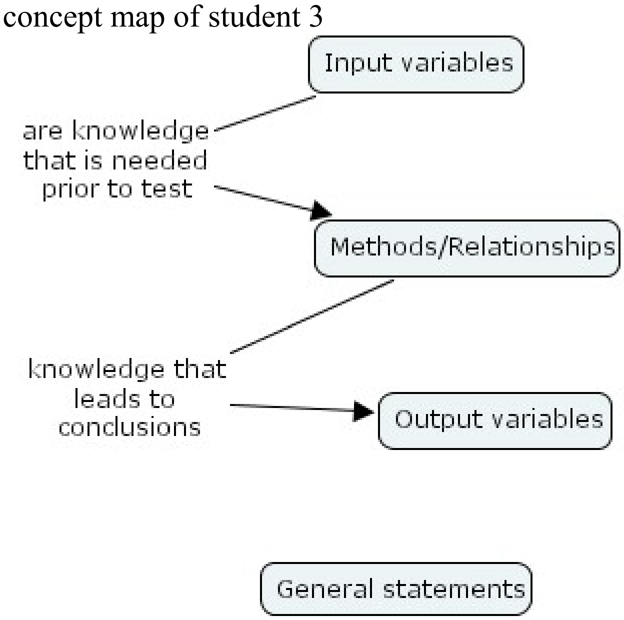

Figure 3: Expert's concept map

The organizational framework appears to be one of 'test design.' Thus, it has input variables (knowledge premises) that are needed if one is to design the test using key concepts about methods and relationships among objects to be tested. Finally, output variables, conclusions are drawn from the test.

The map of the knowledge organization tool in Figure 4 does not appear to reflect, at this level of the hierarchy, an organizational framework such as the relationships of the learning task in the subject domain.

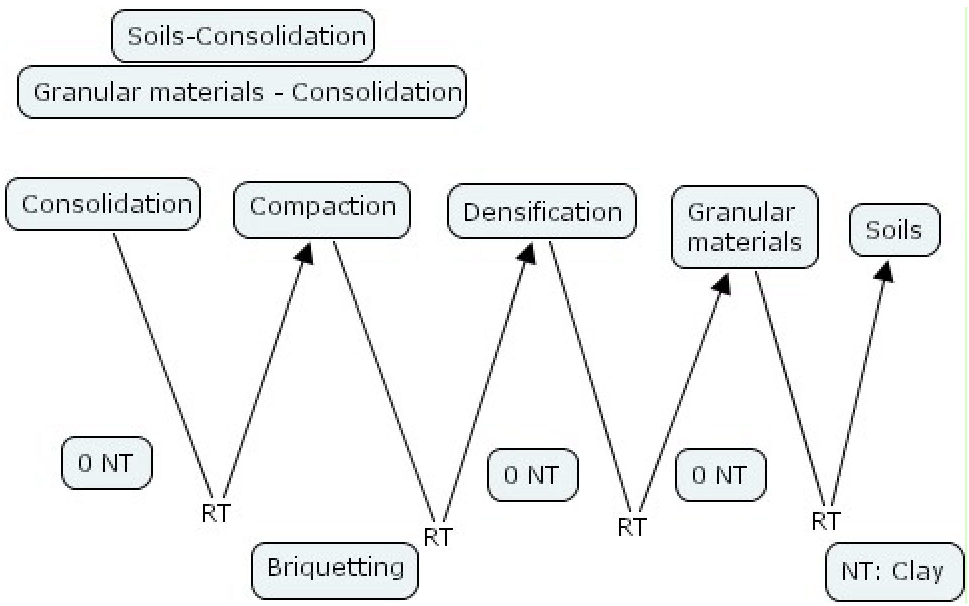

Figure 4: Concept map of EI Thesaurus (term: consolidation)

Similarities and differences: In pathfinder network analysis, the similarity rating examines the degree to which the same concept in two networks is surrounded by similar neighboring concepts. The networks of the novices were compared to the networks of the expert and used to calculate similarity.

Student 1	Student 2	Student 3	Student 4	Student 5	Student 6	Student 7	Student 8	Student 9	Student 10	Expert
3	6	11	6	7	6	5	9	6	6	3

Figure 5: Counts of categories by novices, expert and tool

The number of categories from the final interview and card sort are shown in Figure 5. In general, the knowledge structures of novices exhibited higher similarity to each other. Novice networks showed little similarity and correlation to those of the expert and the tool. Figures 6 and 7 illustrate that the networks of the expert and the thesaurus also showed little similarity and correlation to each other. In order to ensure that the structural knowledge representation is typical of the field, the expert's map and network is currently being compared with other experts.

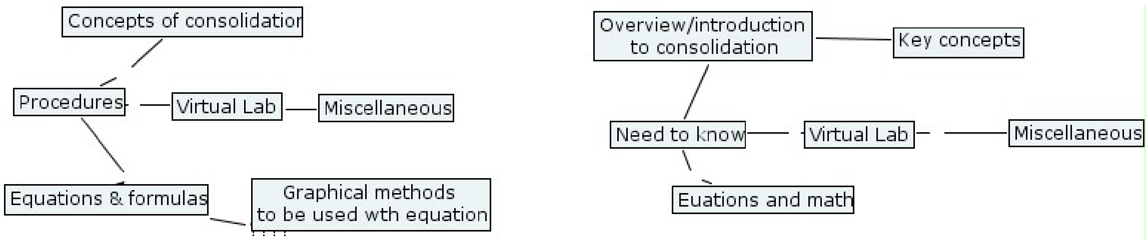

Figure 6: High similarity between novice networks

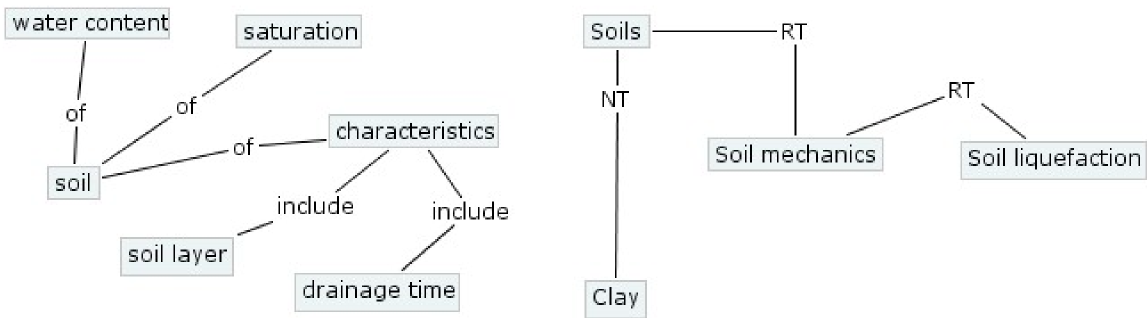

Figure 7: Low similarity between expert and tool (minimalist network)

5. Conclusion:

Many knowledge organization tools in libraries, including thesauri, have been created for diverse groups of users (for example, based on discipline, culture, or age). We have been less eager to accept or accommodate intellectual diversity in our users; by intellectual diversity we refer to the needs of users who start as domain novices. Do our controlled vocabulary tools help such progression? Usually, we have been pre-disposed towards the expert. In fact, both literary and user warrant privilege the expert. The novice maps and networks found in this study show that structural knowledge is an important mediator of subject domain knowledge. Knowledge organization tools and digital libraries may want to consider adding learning schemas and organization frameworks in the representation of concepts and relationships.

6. Acknowledgments:

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7. References:

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