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"WHAT DO YOU KNOW"? ASSESSING CHANGE IN STUDENT CONCEPTUAL UNDERSTANDING IN SCIENCE

*Amy E.Cassata, *Sumitra Himangshu and Richard J. Iuli
University of Rochester, Rochester, New York, USA
Email: riul@mail.rochester.edu

Abstract. This is the initial year of a five-year study that uses concept mapping to assess change in student conceptual understanding at the undergraduate level. The fundamental question being addressed is, "Do students learn science concepts in a meaningful way as a result of taking a science course that melds classroom instruction, field and laboratory techniques, and cooperative learning?" The current study aims to assess change in student conceptual understanding as a result of attending a selected course. Student selection was based on learning approaches as measured by a self-report questionnaire. Concept maps were developed from student interviews and used to measure change in conceptual understanding in comparison to a baseline map generated from a faculty interview. Qualitative and quantitative analysis of student maps was conducted to measure change in individual knowledge structure. Results based on preliminary analysis indicate that the greatest determinant of increased conceptual understanding over the course of a semester is the students' self-report of approaches to learning and studying. Learning styles, in turn, were reflective of differences in the quality of student concept maps. Concomitantly, the concept maps reflected student gains in content in depth over a semester with respect to an expert map.

1 Introduction

1.1 Assessing Student Achievement (ASA) Project

This research uses concept mapping as an assessment tool to study the effect of faculty teaching methods in undergraduate science courses on student learning. To this end, students in selected courses at colleges and universities across the United States were chosen for in-depth analysis of change in conceptual understanding over the course of a semester. Individual concept maps were analyzed to determine whether students had integrated new science concepts with existing concepts and improved in depth of conceptual understanding. As student learning is dependent on the goals of the instructor, the researchers also used concept mapping to determine the instructor's learning goals and analyze the extent to which the students achieved the instructor's goals.

1.2 Regional Workshop Project (RWP) and its Goals

This study is a part of a National Science Foundation (NSF) – funded national dissemination project – The Regional Workshops Project (RWP) that seeks to train 400 undergraduate faculty in science, technology, engineering, and mathematics (STEM) from across the United States. The RWP aims to establish 20 professional "learning communities" of faculty who 1) Create and deliver undergraduate STEM courses that demonstrate that environmental problem-solving is an integrative, challenging, effective way to engage undergraduate majors and non-majors, 2) Use concepts and field/laboratory techniques suitable for teaching undergraduates how science is done in the real world, and 3) Use research-based knowledge of how to assess student learning and support faculty capacity for development. Using local environmental problems, the RWP Model provides faculty with techniques and practices to improve undergraduate STEM instruction and thereby enhance contexts for STEM education.

1.3 Environmental Problem-Solving Model

Environmental Problem-Solving (EPS) is a model for science education that melds classroom instruction, field and laboratory techniques, and cooperative learning (Haynes, 1991). The model has been used successfully for undergraduate and graduate courses in biology, chemistry, geology, engineering, and environmental science across the United States. The RWP uses environmental impact analysis as a unifying theme to bring together the disparate techniques used by participants into a holistic, relevant problem-solving context. This provides a

* Both authors equally contributed to the research.

model to teach undergraduates how science is really done (learning and applying knowledge in a problem-solving context, "hands-on", teamwork) while students work to address real, local environmental problems.

2 Theoretical Perspectives

2.1 Concept Mapping as a Research Tool

Competence in a domain of knowledge is defined by knowledge that has highly integrated structure around central concepts (Glaser and Bassok, 1989). Concept maps are visual representations of meaningful relationships between concepts and linking propositions. They offer an effective way by which to assess student understanding by providing evidence of the quality and accuracy of propositions applied by the individual in the process of higher-order thinking. Concept maps provide a "workable representation" of knowledge and can be used to infer accuracy and depth of knowledge.

Since expertise in a knowledge area is represented by the interconnectedness of knowledge, we chose to construct expert concept maps from structured interviews with faculty. We used each faculty map as a benchmark representing key concepts and expectations emphasized in the target course. We then compared student concept maps to faculty maps at the beginning and end of a semester in order to assess change in student conceptual understanding compared to expert organization of knowledge (Ruiz-Primo et. al., 2001). In addition, we assessed the quality of individual student maps, based on qualitative criteria, in order to evaluate changes in content, accuracy, depth of understanding, and organization of knowledge from the beginning to the end of each course.

2.2 Meaningful Learning

The value of using concept mapping to assess change in conceptual understanding is based on the idea of meaningful learning. Within science education, it is widely accepted that prior knowledge is a key factor that influences learning (Clifton and Slowiaczek, 1981). Meaningful learning, originally proposed in Ausubel's assimilation theory (1963), is in direct contrast to rote learning and involves an act of relating new knowledge to relevant concepts and propositions that are already known. Meaningful learning also involves the ability to link new concepts and their meanings to broader and more comprehensive concepts. In order for meaningful learning to occur, instructional methods have to discourage rote learning by stimulating critical thinking.

2.3 Problem-Based Learning

Problem-based learning environments center instruction around a unifying theme or problem that is relevant to the local community. Structuring science courses around a relevant problem to be solved allows students to see connections to the "real world" and experience science as it is actually practiced. Problem-based learning activities may include a series of integrated field and laboratory exercises, individual assignments addressing local environmental problems, and student written or oral presentations on their findings. The problem-based learning environment provides an interactive setting for students to discuss, debate, build, and present their understanding and hear the perspectives of their peers. As students work together solving problems, ideas are shared and refined, and the experiences translated into robust, usable knowledge (Brown, Collins & Deguid, 1991).

3 Methodology and Materials

Our research design employs mixed methods to collect and cross check assessment data. Both quantitative methods, such as course grades and results of the Learning and Studying Questionnaire (LSQ), and qualitative methods, such as classroom observational data and concept mapping based on faculty and student interviews, were used.

The Learning and Studying Questionnaire (LSQ) examines students' approaches to learning and studying. The LSQ consists of three sections, the first two of which contain items covering reasons for taking the degree program (learning orientations) and reasons for taking a particular course unit or module. The third section is an inventory which produces five scale scores (composites of several items) describing differences in students' approaches to learning and studying. For most of the items in the questionnaires, students respond on a 1-5 Likert scale (5=high). Subscales are formed by adding together the responses on the items in that subscale.

Scoring was done using the EXCEL program. Each item was set as a variable and then a subscale total was produced to create a new variable by summing relevant items.

One year following the NSF-funded regional workshops, approximately ten faculty members were selected from the pool of attendees for in-depth analysis of student learning in a selected course they taught. Case study faculty selection was based on institutional capacity for change, as measured by end-of-year interviews, class size, and institutional demographic diversity. Site visits were conducted at the academic institution of each case study faculty member at the beginning and at the end of a semester. During the first site visit, interviews were conducted with each faculty member for the purposes of identifying and making explicit key terms and essential concepts for students to comprehend upon completing the course. The faculty interviews were transcribed verbatim. The transcripts were used to develop an expert-level concept map.

Student interviews provided an opportunity for students to express their own ways of structuring the concepts they acquired and to give them the opportunity to choose the terms with which to relate and interpret their conceptual understanding. The questions asked provided an open-ended exploration of **what** and **how** the students think. The LSQ gave context and background against which responses gained significance. All interviews were subsequently transcribed and the transcripts were used to generate concept maps. Training faculty and students to construct concept maps was not possible due to time constraints, and therefore warranted construction of concept maps by the researchers.

Between two and ten students from each course were selected for in-depth analysis of change in conceptual understanding over a semester. Because change in conceptual understanding can be influenced by individual differences in approaches to learning as well as interaction with an environmental problem-solving curriculum, LSQ scores were obtained to provide a measure of individual learning approaches. Student selection was based on capacity for change, operationally defined as a lack of strong preference for either a surface-learning or deep learning approach indicated by self-reported endorsement of the use of both strategies to a similar degree. Each student selected participated in 30-minute interviews at the beginning and end of the semester. The interviews, based on concepts elicited in the faculty map, probed understanding of specific concepts and concept relationships. Student interviews were audio-taped, transcribed verbatim, and concept maps were generated from these transcripts (Figure 1). After the completion of the final interview, students received compensation for their participation.

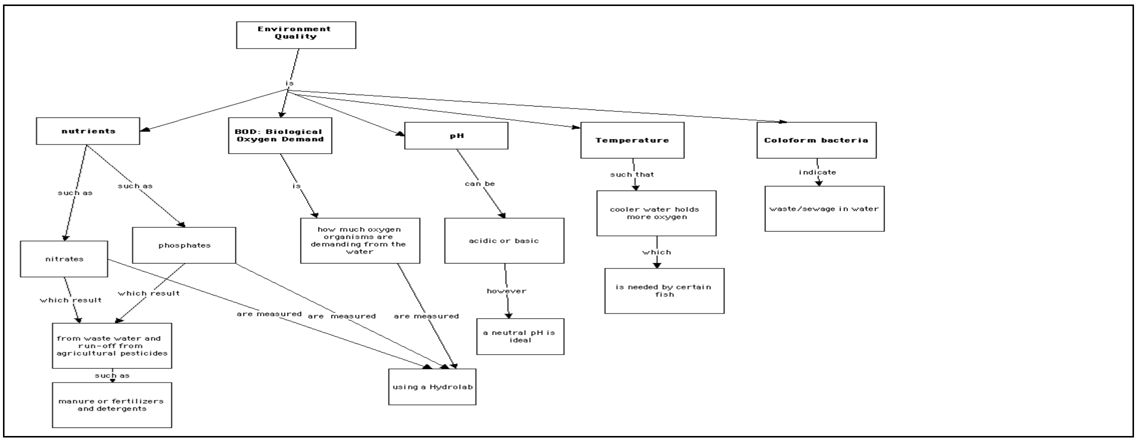

Figure 1. An Example of a Student Concept Map from an Environmental Science Course.

Data analysis of student concept maps addressed both ipsative comparisons (examining the change in quality of concept maps from the beginning to the end of semester for each student) as well as criterion-referenced comparisons (examining the similarity of the student maps to a faculty "expert" map at the beginning and end of semester). Maps were closely examined for accuracy by calculating the percentage of correct propositions in the faculty map that were also present in the student map. The percentages of correct propositions in the student map were compared at the beginning and end of semester to indicate a measure of growth in conceptual understanding. In addition, concept map scores were compared to student course grades as evaluated by the faculty.

4 Results

Learning and studying approaches were evenly distributed throughout the sample (n=20), consisting of 25% deep (conceptual learners), 45% mixed (use both conceptual and rote approaches), and 30% surface learners (rote memorizers). Correlation analysis between learning style and course grade was significant, with the deep learners more likely to obtain a higher grade compared to surface or mixed learners ($r=.711$, $p<0.001$). This finding was substantiated by qualitative measures of conceptual understanding.

Qualitative comparisons were made between pre and post concept maps for each student. With respect to attainment of main ideas as defined by faculty, 100% of deep and mixed learners demonstrated a clear grasp of the main ideas by the end of semester; however, only 84% of the surface learners demonstrated this knowledge. Although a large proportion of mixed and surface learners showed improvement in organization of concepts, overall, the greatest level of improvement was demonstrated by the mixed group. Depth of understanding was reflected in 100% of the deep and 75% of the mixed learners through linkages between broad concepts. However, only 16% of surface learners were able to link broad concepts. In addition, among surface learners, 50% of end-of-semester maps contained inaccuracies, while the maps of only 20% of students designated as deep and mixed contained inaccuracies.

Analysis of student maps in comparison to faculty maps reflected gains in number of concepts as well as depth of understanding (represented by linkages between concepts) between pre- and post-concept maps for the majority of students. Data indicated a significant, positive correlation between number of concepts and depth of understanding on pre- and post-maps ($r=.905$, $p<.001$). Irrespective of the level of course offered, 75% of both upper and lower-level students demonstrated gain in conceptual understanding as measured by the concept maps.

5 Conclusions and Implications for Future Directions

Data from this first year of the study indicate that concept maps can be an effective tool for measuring change in student conceptual understanding in undergraduate science courses. Both quantitative and qualitative criteria, in addition to individual differences among students, need to be considered when scoring student maps. The results indicate that concept maps provide a visual means of representing potential inaccuacies, relationships between concepts, and organization of knowledge, factors which are not easily addressed using traditional assessment tools. Such factors have broad implications for assessing conceptual understanding in undergraduate science education. They enable educators to examine key processes that help students make meaning of scientific concepts and integration of the concepts into pre-existing knowledge bases. We anticipate that our study will provide a model for future studies that seek to use concept mapping as novel tool for assessing change in conceptual understanding.

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