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FORMATIVE STRUCTURAL ASSESSMENT: USING CONCEPT MAPS AS ASSESSMENT FOR LEARNING

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Abstract. Within the educational community, there is an increasing recognition of the need for formative assessment tools. Effective formative assessment must meet four criteria: it must assess higher order knowledge, identify students' strengths and weaknesses, provide effective feedback, and be easy to use. Although concept maps and other structural knowledge representation techniques have been used successfully in a variety of ways, we believe that their utility in formative assessment has not been fully explored. In this paper, we review evidence which suggests that structural assessments, including concept maps, meet the criteria of effective formative assessment. We then describe a proposed computer-based formative assessment system that uses concept maps as the basis of feedback and individualized remedial instruction.

1 Introduction

Since the initial recognition that human knowledge is semantically structured in a relational manner, node-link networks such as concept maps have been used to represent individual's knowledge for a variety of purposes including instructional design, as a learning strategy, and for assessment of student achievement. Among these, assessment has arguably received the least attention and the use of concept maps for *formative* assessment has been particularly sparse. However, evidence suggests that concept maps do have promise for being used effectively for formative purposes. The aim of this paper is to summarize this evidence and describe how we propose to utilize concept maps in the creation of an effective and easy-to-use formative assessment system.

2 Formative Assessment

Within the field of education there has been a shift from using assessment primarily to rank students to using it formatively to improve student learning (McTighe & Ferrara, 1995). Here we define formative assessment as the use, by student and/or teacher, of feedback from an assessment to improve the knowledge of the assessed student on the assessed topic. As can be seen in this definition, formative assessment is a *process* – of assessing, providing feedback, and acting on the feedback in a way that improves knowledge. In order to be effective, then, the formative assessment process must first validly assess relevant knowledge. But what is meant by relevant knowledge? The National Research Council has recommended that assessment should evaluate how a student organizes acquired information, i.e., their conceptual knowledge (2001). This recommendation is based on the recognition that successful application of knowledge depends on an organized understanding of learned material. Consistent with this recommendation, Shepard (2009) argues that valid formative assessment must focus on higher-order, transferable, conceptual understanding as opposed to lower-order rote memorization.

Formative assessment must also be specific. That is, it must identify a student's *particular* strengths and weaknesses. If it does, then a teacher (or the students themselves) can potentially provide individualized remedial instruction in an effort to improve each student's learning. But, even if the assessment is specific, there is no guarantee that the feedback that it generates will translate into effective remediation. Heritage, et al. (2009) have shown that teachers are more adept at identifying students' strengths and weaknesses than they are at deciding how to use such specific feedback in order to modify subsequent instruction. Thus, the formative assessment process must provide effective feedback for remediation.

Finally, the entire formative assessment process must be easy to use if it is to be implemented in the classroom. Indeed, the National Research Council (1999) has found that many teachers view formative assessment as an unnecessary addition to their already heavy workloads. We suspect that students may feel the same. Thus, formative assessment must be user friendly if it is to have a chance to succeed.

To summarize, we believe that the formative assessment process must: 1) assess higher-order knowledge, 2) identify a student's specific strengths and weaknesses, 3) provide feedback that can be used to effectively improve learning, and 4) be user friendly. Next, we discuss the potential shown by structural assessment techniques, such as concept maps, to meet each of these four criteria.

3 Structural Assessment as Formative Assessment

3.1 Assesses Higher-Order Knowledge

It may be evident that structural assessment techniques, such as concept maps, measure the structure of one's knowledge. But, it may not be as obvious that the structure of one's knowledge is an indicator of higher-order, conceptual understanding. Goldsmith and Johnson (1990), however, have provided evidence in this regard. They have shown that the degree of similarity between student and referent knowledge structures is significantly positively correlated with more traditional measures of domain knowledge, such as course grades and exam performance. Perhaps more importantly, they showed that the quality of one's knowledge structure is more strongly correlated with performance on more conceptual, higher-order measures (e.g., essays) than on lower-order measures (e.g., multiple choice exams). As well, others have demonstrated that knowledge structure is related to higher-order skills such as problem solving, drawing inferences, and transfer (e.g., Trumpower & Goldsmith, 2004). Therefore, structural assessment techniques do appear to be valid measures of higher-order knowledge, thereby satisfying the first criteria of a formative assessment tool.

3.2 Identifies Strengths and Weaknesses

Typical schemes for evaluating the quality of knowledge structures generate overall measures, such as the degree of similarity between a student and referent concept map. Such measures are useful for summative assessment, but less useful for formative purposes. For formative assessment, more specific information is required. Recently, Trumpower, Sharara, and Goldsmith (2010) have demonstrated the specificity of information provided by structural assessments. In their study, undergraduates with no prior training in computer programming learned about a simple computer programming language. Later, they were tested for their structural knowledge of the language, as well as their application of the language on a series of problem solving tasks. The problem solving tasks were comprised of two different types of problems. Task analysis indicated that performance on one type of problem required knowledge of the relationships between the programming concepts of *If-then*, *Go-to*, and *Step*. Performance on the other type of problem, however, required knowledge of the relationships between the concepts of *Pointer*, *Position*, *Increment*, and *Assign*. It was found that students whose knowledge structures contained links between *If-then*, *Go-to*, and *Step* performed better on the former type of problems than students whose knowledge structures did not contain these links. Likewise, students whose knowledge structures contained links between *Pointer*, *Position*, *Increment*, and *Assign* performed better on the latter type of problems than did students whose knowledge structures did not contain these links. Therefore, it seems that assessment of specific links in students' knowledge structures can be used to identify specific conceptual strengths and weaknesses.

3.3 Generates Effective Feedback

Although knowledge structures may be able to identify specific conceptual misunderstandings, students and their teachers may not be able to capitalize on such information to remediate the identified misunderstandings. Trumpower and Sarwar (2010) have shown the efficacy of using structural assessment to improve understanding. In their study, high school physics students' structural knowledge of a particular unit of instruction was assessed following completion of the unit. As feedback, students were shown their knowledge structure in the form of a concept map, as well as a referent concept map. They were asked to reflect on any discrepancies between their map and the referent map. In addition, results from the structural assessment were used to identify specific misconceptions regarding concept relationships and to subsequently create individualized remedial exercises (e.g., problems to be solved) for each student. Following this feedback/remediation phase, students' structural knowledge was reassessed. It was found that students' structural knowledge of the unit significantly improved. This finding indicates that structural assessments can generate effective feedback. However, it is unclear whether the feedback was effective by being given directly to the students for reflection or by allowing instructors to create individualized exercises for each student.

In a subsequent study, Sarwar and Trumpower (2010) used a structural assessment to generate three different remediation conditions. In one condition, physics students were provided with a concept map based on their structural knowledge along with a referent concept map and asked to reflect on any discrepancies. In a second condition, example problems were created to illustrate the concept relationships depicted in the referent concept map and were provided to students to study. In a third condition, multimedia presentations were created to illustrate the concept relationships depicted in the referent concept map and were provided to students to study. As in the previous study, students' conceptual knowledge was assessed before and after the remediation conditions were provided. Although significant improvement was found following each type of remediation, it was significantly greater in the reflection condition. These findings have several implications. First, concept maps do provide feedback that can be used to create effective remedial instruction. Second, even if teachers do not use it to create remedial instruction, students seem able to use it effectively themselves for self reflection.

3.4 Is User Friendly

Formative assessment is not likely be implemented in the classroom if it is not easy to use. So, evidence that knowledge structures can validly assess higher-order knowledge, identify specific strengths and weaknesses, and generate effective feedback is irrelevant unless a formative assessment process based on structural knowledge can be devised that is user friendly. Fortunately, there is evidence that concept maps are easily used by students in a formative capacity. Schacter, et al. (1999) asked eighth grade students to generate concept maps, given a set of environmental science concepts. They were also asked to search through information provided to them in an internet-like environment in order to add relevant content links to their concept maps. Feedback concerning the quality of their concept maps (based on similarity to a referent concept map) was made available upon request. It was found that students, on average, accessed feedback five times during their 50 minute session.

In a subsequent study using the same learning environment and task, but with teams of students rather than individuals, it was found that frequency of use of feedback was significantly positively correlated with a conceptual knowledge outcome measure (Hsieh & O'Neil, 2000). These studies demonstrate that feedback which highlights discrepancies between student and referent concept maps is relatively easy to use by students (as indicated by the frequency of use in Schacter, et al., 1999) and is effective (as indicated by the outcome measure in Hsieh & O'Neil, 2000). These studies do not, however, provide any indication about how easy it is for teachers to implement such a feedback process. In order for teachers to use knowledge structures formatively in the classroom, we believe that the entire process must be as automated as possible. Therefore, we propose the following system.

4 Proposed Formative Structural Assessment System

Our proposed system involves four stages: structural assessment, evaluation, feedback, and ongoing instruction. In the initial stage, students' structural knowledge is assessed by having them complete a computer-based concept mapping task. The set of concepts to be used in the concept map is chosen by the teacher. By using a predetermined set of concepts rather than allowing students to choose their own, the evaluation and ongoing instruction stages in the system are more automated, as will be seen briefly.

In the second stage, the student's concept map is evaluated by comparison to a referent concept map. More specifically, each conceptual link that is present in both the student and referent maps (referred to as *germane propositions*) and that is present in the referent map but not in the student map (referred to as *missing propositions*) will be recorded by the system. The results of this evaluation will be used to create feedback and ongoing instruction presented in the next two stages. It should also be noted here that the referent map will be provided by the system. Much like textbook publishers provide test banks, our system will have a repository of referent concept maps, created by teams of subject matter experts, corresponding to different units of instruction in various subject areas.

In the third stage, students will be shown their concept map augmented by any additional missing propositions, highlighted by dotted lines (Figure 1). In our system, concept maps provided as feedback will have unlabeled links.

Students will be told that missing links indicate concept relationships that they may not have fully understood or considered. They will then be asked to consider ways in which the concepts linked by dotted lines might be related and to give examples if possible. Students will be prompted to write their responses in space provided.

In the fourth stage, the missing propositions will become active. Students will be instructed to click on the dotted lines for additional instruction intended to help them understand some ways in which linked concepts are related. This additional instruction may be comprised of text, problems, examples, and/or multimedia content. The system will contain a variety of such instructional content to illustrate the concept relationships indicated by each proposition in the referent concept maps. As with the repository of referent concept maps, this content will be created by teams of subject matter expert.

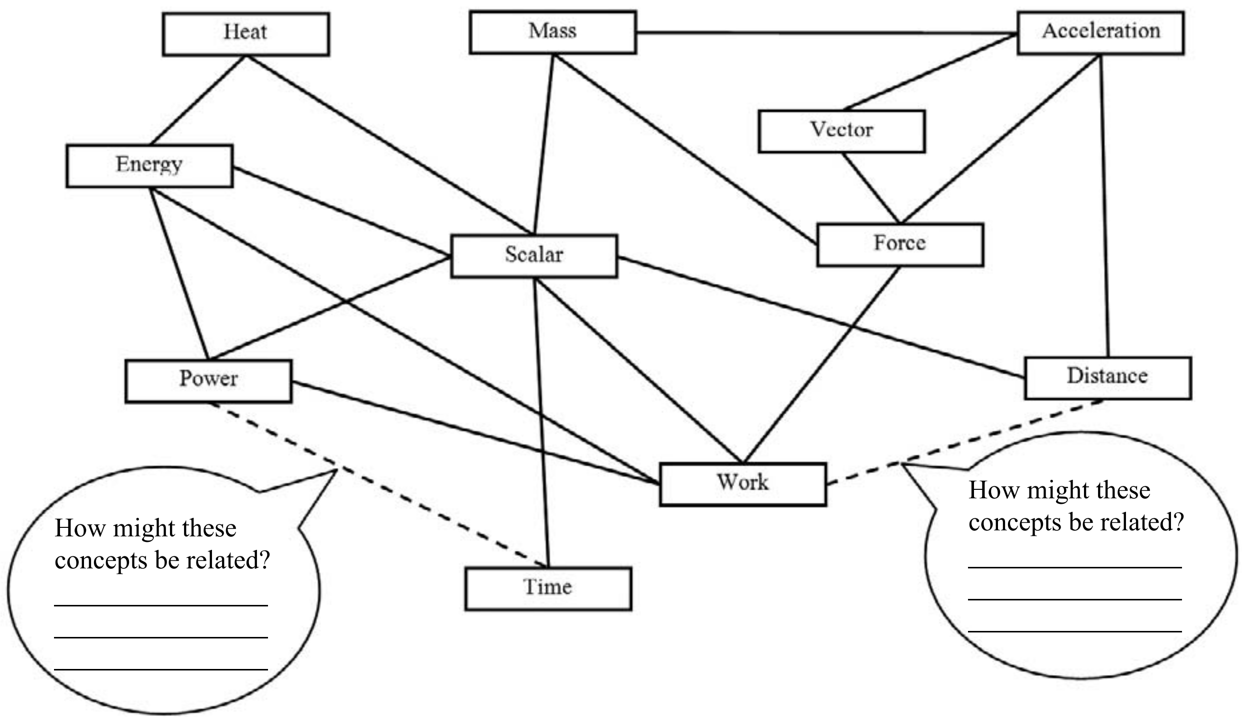

Figure 1. Student concept map with propositions present in the referent map but not in the student map highlighted with dotted lines.

As can be seen, the only input required of the system from teachers (after the initial input of subject matter experts to create the system's referent concept maps and associated instructional content) is the choice of a set of concepts to be assessed. Thus, although we are in the early phase of building and user testing the system, it would appear to be very user friendly for teachers. Also, because it is based on the research and principles of effective formative assessment discussed earlier, we believe that it can successfully improve student's conceptual understanding.

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