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# Knowledge Maps and Their Application to Student and Faculty Assessment

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**Abstract** - This paper discusses the development of Knowledge Maps for enhancing engineering learning. These maps are somewhat similar to concept maps, which have been widely used and developed in various areas of study. Knowledge Maps, however, extend concept maps in that they not only illustrate the underlying concepts of a discipline, but they actually embed the knowledge in each of those concepts through various multimedia attachments. Knowledge maps also allow reverse mapping so that students can be assessed based upon how many concepts they know and whether they have understood the proper relationships between the concepts. A reverse map can be used to evaluate students and act as a record of student learning. Aggregate course maps may be used to gain an average understanding of the gains of entire classes of students and may be used to evaluate faculty effectiveness and provide valuable insight into the gains and weaknesses of students matriculating from one course to the next. The work contained herein presents the strategies implemented to allow for the design of custom knowledge maps. Reverse mapping techniques are discussed to indicate the method for evaluation of students.

**Index Terms** - Assessment, concept inventories, concept maps, grading, knowledge maps, student feedback.

## INTRODUCTION

The traditional model for formalized engineering education begins by providing some sort of instruction and reading assignment for students to learn concepts and information, providing exercises aimed at reinforcing concepts and providing further illustration and insight into the concepts, and then assessing student knowledge formally through graded assignments and exams. The classic view of such learning is that it exists in an isolated environment; that is to say that all instruction about a particular concept comes from the material presented within the confines of the course and all assessment within the course should evaluate only the concepts presented by the instructor or contained within the assigned reading. This model, however, fails to capture the incredibly detailed process undertaken by students raised in the internet generation who have access to vast digital resources, many of which are not introduced into the learning process by the instructor. In recent publications

such as the Engineer of 2020[5] and Educating the Engineer or 2020[6] the National Academy of Engineering recognizes that the paradigm needs to shift in engineering education and the current models for engineering curricula lag behind the available technology.

There is a very significant shift, however in the educational community away from an instructional paradigm to a learning paradigm [1][2]. Education researchers are finally discovering that the traditional model supports a means to an end as the primary objective rather than the end itself. For years, educational institutions, particularly undergraduate institutions[2] have viewed their role to be to provide lecture and instruction. The new paradigm, however, recognizes that the primary focus of education should be ultimately the end result, that is student learning. Indeed the criteria for accrediting engineering programs, as proposed by ABET[4] focuses on the outcomes and the abilities students are expected to garner during their course of study in an engineering program. Why should educational institutions be tied to a process alone when the process should only serve to facilitate the ultimate purpose?

While this paradigm shift began in the mid 1990s[2], and significant progress has been made to incorporate changes in the curriculum to promote learning, there is still much work to do. Students still tend to be evaluated based upon their completion of various assignments rather than the actual knowledge they obtain. Faculty members are still evaluated largely based upon their ability to draw in research dollars and the achievements they can boast on a vitae rather than the results they garner from their students in terms of students' overall learning achievement. In this paper a new assessment framework is introduced whereby student and faculty assessment may be done in a manner that is based upon the learning that takes place, not the manner in which that learning occurs. Our belief is that this shift in paradigm will encourage more inquisitive learners, better teaching, and passion for knowledge acquisition rather than obedience to the rules set forth by an instructor.

## GRAPHICALLY REPRESENTING KNOWLEDGE

A learning centered approach to assessment begins with the development of a complete representation of the body of knowledge students are expected to acquire. This is done through the construction of expert knowledge maps. Knowledge maps are similar to concept maps, which were

originally developed by Joseph Novak in 1972[3]. Concept maps are directed graphs which represent various concepts and the relationships between them in a very organized manner. Novak's work has continually evolved over the last 35+ years and has taken a constructivist approach to learning and the modeling of knowledge. This constructivist view holds the belief that the ability to learn new concepts is based strongly on the ability to assimilate new information into one's existing structure and representation of knowledge. This modeling of knowledge fits well within the model of engineering education proposed by Radcliffe[7], which takes a Gestalt approach to education stating that the sum is indeed greater than the parts and newly acquired knowledge will be of much greater benefit if they can see how this newly acquired knowledge fits within their existing knowledge framework.

The Institute for Human and Machine Cognition has developed the software utility CmapTools[9] which provides the foundation for this work. Using CmapTools, one may map out the various concepts taught in a course, in a single lesson or unit of a course, or even in an entire degree program. These maps allow one to graphically depict the relevant topics in a discipline and the relationships that exist between these topics.

#### **EXPERT KNOWLEDGE MAPS**

The first step in this new learning-centric evaluation paradigm is to establish an expert knowledge map. An expert knowledge map is a concept map developed by someone with a strong working knowledge of the discipline to be mapped. Such an expert could include a research or an instructor. The distinction between a concept map and a knowledge map is made because these maps not only outline the various concepts and relationships involved in the discipline, but they also embed the knowledge of the discipline within the map. The goal of embedding knowledge within the map is achieved by linking each node or vertex in the map to content such as power point slides, pdf files, multimedia content, or websites relevant to the topic at hand. The embedding of such content allows one who is not an expert in the field to be able to view the map of an expert and obtain some of the knowledge of the discipline. A single instructor may develop these expert maps, but ideally these maps are developed in collaboration with other instructors and researchers so that a common representation and foundation for teaching is established. These maps should be carefully constructed in order to include all the relevant concepts involved in the material being taught to students so that an adequate assessment may be done.

#### **DEVELOPING ASSESSMENT TOOLS**

After the expert map is established to represent all the concepts and relationships an instructor hopes to teach students and they have deployed that knowledge to their students in some way, an assessment of that knowledge is needed. The second step in the process is to develop an

assessment of student knowledge. This can be done by developing a concept inventory to evaluate student understanding of the concepts involved. Concept inventories are multiple choice tests designed to evaluate student understanding of concepts and the relationships between them and they provide an ideal correlation with concept maps.

The development of a concept inventory can be a tedious process. Concept inventories are typically developed for entire disciplines and require years of collaboration and revision in order to achieve robustness. For purposes of student evaluation, however, much simpler concept inventories can be developed by an instructor in a manner very similar to how the expert knowledge map is generated. The development includes a thorough assessment of the concepts to be presented in the course or lesson and the creation of a question that tests the knowledge of each of these concepts and their relationship with other concepts.

Concept inventories should be multiple choice assessments to allow for clarity in student responses and to reduce the time needed to evaluate the results of such an assessment. While the development of a proper question set is vital to the quality of the concept inventory, the development of the proper multiple choice options is perhaps more important.

#### **CASE STUDY**

The author developed an expert concept map and a concept inventory for a two-week mechatronics unit which is part of a large freshman engineering course at Virginia Tech. The approach to developing the multiple choice options for the assessment developed by the author was to begin by pilot testing the concept inventory questions in a free response format. This pilot test allowed the author to see how student responses varied and to identify how students articulated their responses, be they correct responses or incorrect responses. The correct responses served as a good basis for the proper wording of the correct option in the multiple choice answer list and the incorrect responses served to provide the set of incorrect choices for each of the questions in the concept inventory. In order to get unbiased results from students, the pilot test of the concept inventory was done before students were given any of the course materials or instruction on the topic to be tested.

The pilot test was deployed via an optional 14-question online survey and feedback was obtained from 106 freshman engineering students. Students took the survey at their leisure and were not proctored while doing so. The questions in the survey asked very conceptual questions about the topics to be covered including questions about energy, mechanical components, electrical components, electrical theory, and Boolean logic. Students were instructed that they were not being evaluated and their grade in no way was tied to their responses on the survey. They were also instructed that they were free to guess or to simply

state that they did not know the answer to any of the questions. Student responses varied quite significantly.

As an example, one question asked “What is a gear and what are gears used for?” Some examples of the answers given by students include: “a toothed wheel used in inventions,” “a gear is like a sprocket, that spins and is used in a number of different ways generally as a tool to turn other devices,” “for working a machine,” and “not absolutely sure.” Another questions asked “What does it mean to connect components in parallel?” A sample of some student responses included: “beside each other, not connected or based on each other,” “breaks off into different loops,” “it has to do with wiring,” and “Parallel connection means each component has its own connection to the power source so if one component is removed the circuit remains intact.” One student even tried to use the characters on the keyboard to graphically depict components in parallel in a circuit as depicted in Figure 1.

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I----VVV----I
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I__VVV__I

```

FIGURE 1

A STUDENT USED ASCII ART TO DEPICT TWO RESISTORS IN PARALLEL

As can be seen from just this small sampling of student responses, the level of understanding of students varied significantly and their mental model for the concepts involved in the unit also differed. These student responses to all of the survey questions are currently being used to develop a more robust questionnaire, which will include multiple-choice options.

### GENERATING STUDENT KNOWLEDGE MAPS

As was previously mentioned, the answers to each question in the concept inventory are correlated with a node or vertex within the knowledge map. A correct answer to a question on the concept inventory, therefore, signifies that a student has learned that concept or developed an understanding of that relationship. A student map can be generated to represent the portion of an expert map that a student has mastered. The student map would show gaps for any concept or relationship that the inventory indicated the student did not know. A hypothetical example is depicted in Figures 2 and 3. For purposes of this example, concepts are generalized as 1, 2, 3, etc and relationships between concepts are generalized as A, B, C, etc. This generalization is done to show that this method may be applied to any concept or relationship. Figure 2 shows a very simple expert map containing six concepts (i.e. 1-6) and six relationships (i.e. A-F) between concepts. Figure 3 shows a student map indicating that the student had mastered concepts 1, 3, 4, 5, and 6, but did not have a mastery of concept 2. The student map in Figure 3 also indicates that the student has a working knowledge of relationships A, C, D, and E, but did not have working

knowledge of relationships B or F. The student map in Figure 2 would be generated if a student failed to answer a question correctly that corresponded with concept 2 and relationship F. The student may have answered a question incorrectly about relationship B also, but it would be impossible for the student to have knowledge of a relationship between concepts when they do not have knowledge of both concepts. Thus, the lack of mastery of concept B leads to the automatic removal of relationship B regardless of what answers the student gave to questions corresponding to relationship B in the concept inventory.

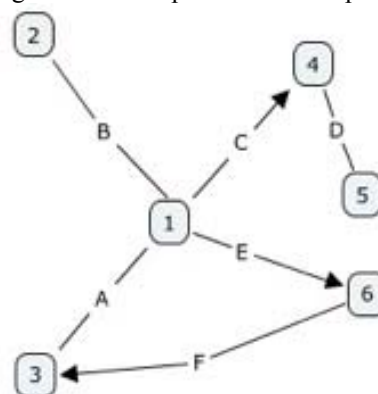


FIGURE 2

A GENERIC EXPERT KNOWLEDGE MAP

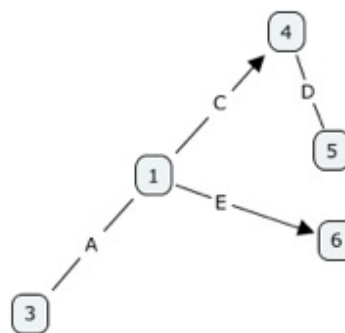


FIGURE 3

A GENERIC STUDENT MAP BASED ON THE EXPERT MAP IN FIGURE 1

### WEIGHTING OF CONCEPTS AND RELATIONSHIPS

In order to gain mastery of a subject, mastery of certain concepts are more important than mastery of other concepts. The same expert who developed the expert mapping for a course or particular unit could also weight each of the concepts accordingly. In the map given in Figure 1 it can be seen that most all other concepts are somehow related to concept 1, thus concept 1 seems to be the most important concept and may be weighted as such. Relationships A, B, C, and E branch off of this very important concept directly so they also are seemingly very important. The weighting of these relationships would ideally be done in an objective manner, but such weighting is ultimately subject to the importance an instructor places on each concept and relationship which will vary from expert to expert. Ideally

such weighting would be done in consultation with a panel of experts. Figure 4 shows a potential weighting of the concepts and relationships contained in the expert map of Figure 2.

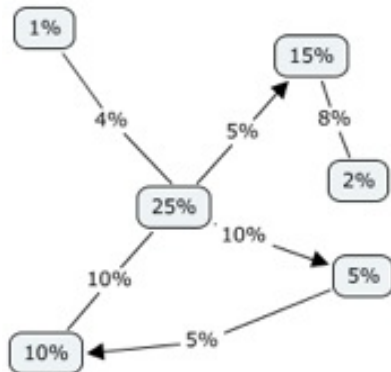


FIGURE 4  
POTENTIAL WEIGHTING OF THE CONCEPTS IN FIGURE 1

This weighting structure shows that mastery of the central concept is worth 25% while mastery of other less important concepts are worth as little as 1%. The student's score on a particular assignment could thus be based on the nodes represented in their student map as compared to the nodes represented in an expert's map. Thus, looking back to the student map depicted in Figure 2, the student is missing concept 2 (1%) and relationship B (4%) and F (5%). The student's grade for this particular assessment would thus be 90% (100% minus the total deductions for each missing link and node in the student map). This can be correlated to a standard grading scale and the student would thus earn an A-.

#### AGGREGATE CLASS MAPS

Instructors may wish to determine the overall performance of their class. This evaluation can be done by developing an aggregate student map. In software each node and link in all of the student maps in the course may be counted to determine how many students had each node present or missing in their student map. It may be that all students had a mastery of the most centralized concept, 1, but students typically missed concept 3 and relationship F. This may indicate that the way such concepts and relationships are taught should be modified in the future to improve overall student understanding. A comparison between the aggregate class map for instructors teaching the same course may be done in order to compare the effectiveness of various instructors at teaching the same material and may indicate areas where collaboration may improve the overall effectiveness of both instructors.

This strategy can be utilized to compare the learning done by students in the same course with sections taught by two different instructors, Instructor1 and Instructor2. As an example of this, suppose the following 3 student maps (Figures 5-7) were generated from student responses in

Instructor1's section of a course. Likewise, Figures 8-10 depict three student maps for students of Instructor2. For simplicity, assume each instructor has only 3 students in their class.

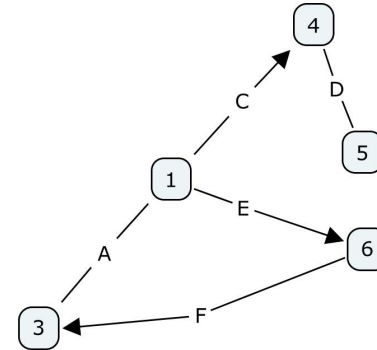


FIGURE 5  
ONE STUDENT MAP FROM INSTRUCTOR1'S SECTION OF A COURSE

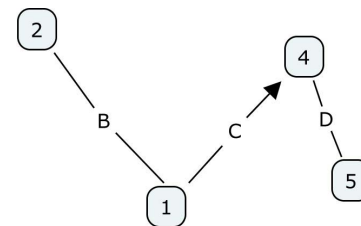


FIGURE 6  
A SECOND STUDENT MAP FROM INSTRUCTOR1'S SECTION OF A COURSE

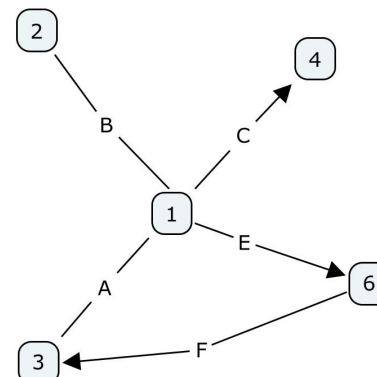


FIGURE 7  
A THIRD STUDENT MAP FROM INSTRUCTOR1'S SECTION OF A COURSE

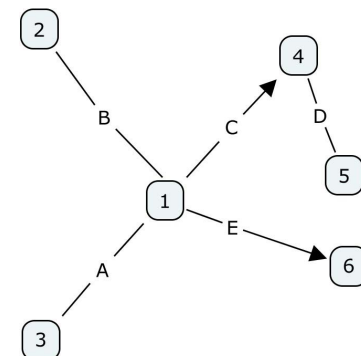


FIGURE 8  
ONE STUDENT MAP FROM INSTRUCTOR2'S SECTION OF A COURSE

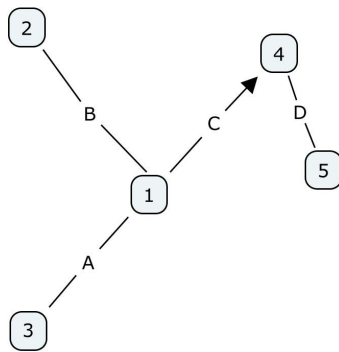


FIGURE 9

A SECOND STUDENT MAP FROM INSTRUCTOR2'S SECTION OF A COURSE

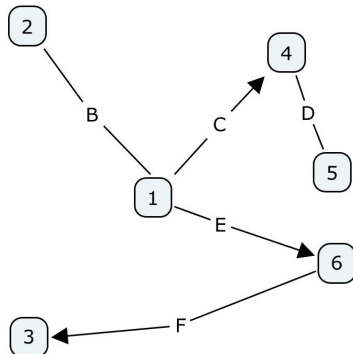


FIGURE 10

A THIRD STUDENT MAP FROM INSTRUCTOR2'S SECTION OF A COURSE

The aggregate student map for Instructor1 and Instructor2 is thus depicted in Figures 11 and 12 respectively. Note that this map depicts both the total number of students in each instructor's class who demonstrated mastery of the corresponding concepts and relationships and the percentage of students with which this corresponds.

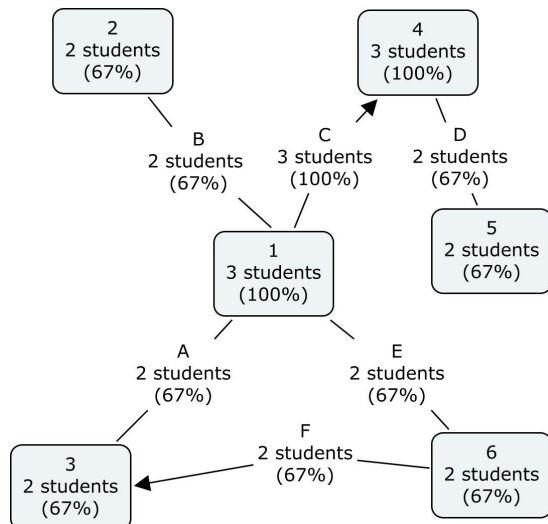


FIGURE 1

AGGREGATE KNOWLEDGE MAP FOR ALL STUDENTS IN INSTRUCTOR1'S CLASS

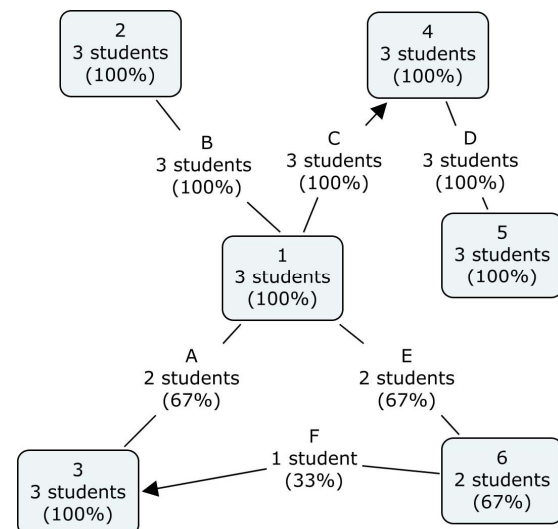


FIGURE 2

AGGREGATE KNOWLEDGE MAP FOR ALL STUDENTS IN INSTRUCTOR2'S CLASS

As can be seen from the aggregate maps in Figures 10-11, all students in both classes demonstrated mastery of some concepts and relationships (ie. Concepts 1 and 4, Relationship C). While it is impossible to demonstrate statistical significance with such a small sample size, there does appear to be a difference in the topics that students in Instructor1's class understood when compared to students in Instructor2's class. These aggregate maps may be much more illustrative of such differences with larger classes.

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