AC 2010-1997: UTILIZING SOFTWARE-GENERATED CONCEPT MAPS BASED ON CUSTOMIZED CONCEPT INVENTORIES TO ILLUSTRATE STUDENT LEARNING AND KNOWLEDGE GAPS

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Utilizing Software-Generated Concept Maps Based on Customized Concept Inventories to Illustrate Student Learning and Knowledge Gaps

Abstract

Concept inventories have been developed for a variety of disciplines over the last 20 years in order to evaluate student understanding of subjects within the discipline at the conceptual level. Concept inventories have served as a basis for evaluation of student's fundamental understanding of topics and students' responses to concept inventories showcase areas where there is need for enrichment. Concept maps are directed graphs that depict the relationships within a discipline and have been used since the 1970s to showcase how knowledge is constructively assembled within a learner's cognitive structure. Concept maps graphically depict the concepts and relationships within a discipline. Typically, concept maps are constructed by students in order to allow evaluators to understanding learners' comprehension of the relationships that exist within a discipline. In this paper software is described that has been developed to couple concept inventories with concept maps in order to elicit graphical representations of students' understanding of a discipline based upon their responses to a custom-designed concept inventory.

This software allows for entry of the questions and answers within a concept inventory and allows each answer to be correlated with a concept or relationship in a concept map. Under this system an expert develops a comprehensive concept map that depicts all of the underlying concepts and relationships within a discipline and then the questions in the concept inventory are tied to the appropriate portions of the concept map. The results of the deployment of the inventory are then depicted in a graphical student map showcasing each individual learner's mastery of the underlying concepts and relationships as a concept map that is a subset of the comprehensive map. The software also generates aggregate maps based upon various demographics so that performance can be examined on both a student-by-student basis and also at a holistic higher level.

This software has been used in conjunction with a course unit on mechatronics designed to introduce first-semester engineering students to the fundamentals of mechanics and electronics. A comprehensive map has been developed and a corresponding concept inventory has been designed to test student's knowledge gains through participation in the course unit. The concept inventory has been given as a pre and post test and has also been given in a subsequent semester to evaluate student retention of conceptual knowledge over time. Over 1400 data sets have been collected and analyzed. Within this paper the components of the analysis software are discussed along with some results from data analysis.

A Brief Introduction to Concept Maps

Concept maps are a way of graphically representing the underlying components of a particular field or subfield or, more generally, knowledge [1]. The concepts are enclosed in circles or boxes and lines or arrows linking the boxes indicate the relationship that exists between the concepts. The lines are labeled to indicate the specific relationship that exists between the concepts using linking phrases such as “has a,” “is a,” “helps with,” etc. Knowledge itself can be considered hierarchical in nature in that certain concepts are developed on other concepts or correlated with other concepts. Concept maps can be used to illustrate how one concept or entity relates to another either directly or indirectly through other concepts and provides a structure for detailed organization of knowledge. Organized knowledge is necessary for effective teaching and effective learning.

Joseph Novak developed concept maps in 1972 at Cornell [1]. The pioneering work on concept maps stemmed from a study on the evolution of children’s knowledge of science over the course of their development. Novak’s work was based on the cognitive psychology work of David Ausubel in the 1960s and 70s [2-4]. The fundamental principle of Ausubel’s model of learning was that new concepts are learned through assimilation. That is to say that in order for someone to understand a new idea they must be able to cradle it into the framework of other concepts they already know, known as their cognitive structure, and find relationships that exist between previously known concepts and the new concept. Jerome Bruner performed similar work noting that in order for learners to solve new problems, they must first categorize them as exemplars of old principles they had previously mastered [5]. Concept maps therefore are visual representations of the underlying structure and the assimilation of new concepts within the existing framework of other concepts. Figure 1 is a concept map about concept maps and showcases the general structure used to represent information.

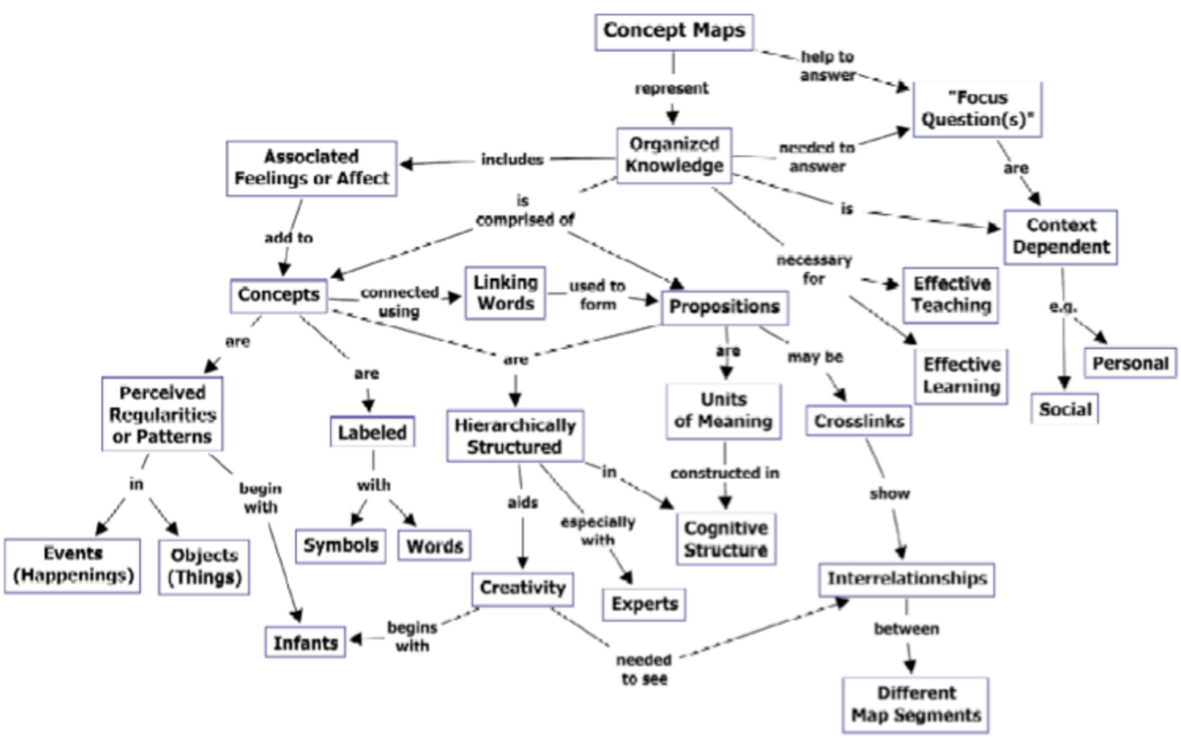

Figure 1 A concept map about concept maps [1]

Concept maps can be used not only to illustrate concepts or show what students should learn, but also as an evaluation tool for learning, evaluating valid and invalid ideas held by learners. Through the formation of each learner's concept map, one can see the links and underlying structure the learner has formed and discover any flaws in logic either with the newly learned concepts or the underlying structure to which it is assimilating. In the Virginia Tech entomology department, students use concept maps to graphically assemble the various concepts and relationships learned in several entomology courses and the maps are evaluated by comparing the student maps to a faculty generated criterion map [6]. A similar tool termed Robograder™ is in use at Michigan State University and involves autonomous grading of student generated concept maps with added flexibility added by searching through a set of synonyms in WordNet to determine if the student responses are semantically equivalent to the criterion map although variances is word choice are made [7].

A Brief Introduction to Concept Inventories

Concept inventories are multiple choice assessments designed to evaluate student understanding of course content at the conceptual level. The first concept inventory, the well-known "Force Concept Inventory (FCI)," was developed by Hestenes, Wells, and Swackhamer in 1992 [8]. The FCI asked students very basic questions about concepts covered by an introductory high school or college physics class. The results of the inventory showed the disparity between understanding of the theory of Newtonian physics and the conceptual understanding of physics students have developed based on their previous life experience and through common sense and intuition. The inventory was purposefully designed to evaluate concepts alone, rather than mathematical ability with questions on the inventory designed to be conceptual in nature rather than computational.

Since the pioneering work of Hestenes et al. several other groups of educators have gone on to develop concept inventories for a variety of fields. The National Science Foundation's foundation coalition [9] tracks the development of concept inventories. In October 2000, work began on concept inventories in the areas of thermodynamics [10], strength of materials [11], signals and systems [12], and electromagnetics [13]. At this time, researchers from multiple universities began collaborating to develop these inventories. In October 2001, research continued in this arena and the development of concept inventories in circuits, fluid mechanics [14], and materials [15] began. At the 2003 Frontiers in Education conference a panel session was held to review the progress toward development of concept inventories in eleven different fields including several of the aforementioned areas along with new inventories in thermal and transport processes, dynamics, chemistry, and statistics [16]. In 2004, work on the Chemistry Concept Inventory was presented at the ASEE/IEEE Frontiers in Education conference [17].

Overall Evaluation System

The authors have developed a system to use concept maps to graphically represent the knowledge each student has of the information in a discipline. Rather than having students draw a concept map representing their understanding of how the various concepts and relationships are related to one another, the system administers a concept inventory to students and uses each student's responses to the concept inventory to develop a concept map representing the concepts and relationships each student knows. The concept inventory can be one of the formalized concept inventories maintained by the foundation coalition or may be custom designed based upon the curriculum. The system takes as input a comprehensive concept map representing all of the concepts and relationships related to the inventory and each student map is a subset of the complete set of concepts and relationships in the comprehensive map representing the subset of the overall knowledge the student has mastered. The system relies upon XML schemas for data storage and parsing. The next two sections discuss the XML schema used to store concept maps and concept inventories, respectively.

An XML Schema for Storing Concept Maps

The Institute for Human and Machine Cognition (IHMC) has developed the .cxl XML schema for representing the data in concept maps in an XML format [18]. This XML schema allows for the storage of all of the concepts, linking phrases, and connections that are embedded within a concept map. Additionally the schema includes information on the layout and appearance of each of the concepts and relationships including information on fonts, line thicknesses, colors, and placement. Within the .cxl format each concept and linking phrase is assigned a unique ID and the appropriate properties are assigned based upon the ID of the map component.

A simple example of the use of the .cxl XML schema is included in Table 1 with line numbers appended to facilitate discussion. This .cxl file is used to represent the very simple concept map depicted in Figure 2, which contains only two concepts and one relationship. Line 1 provides the standard XML header. Line 2 is part of the standard header in the .cxl format. Line 3 contains metadata regarding the creator of the map, contact information, etc and is usually several lines of XML. Line 4 establishes the overall dimensions of the map. Lines 5-8 list all of the concepts in the map and likewise lines 9-11 list all the linking phrases in the map. Lines 12-15 list all the connections between concepts and relationships. In this case there are two connections, one from “Some Concept” to the linking phrase “is related to” and the second connection from “is related to” to “A second concept.” Lines 16-22 are used to store information about the appearance of the concepts and linking phrases including the position and size of each component. The style sheet at the end of the .cxl format is used to establish generic appearance information for each concept or linking phrase that does not have such information explicitly set individually including fonts, colors, line thicknesses, and preferences regarding the use of arrows in the maps. This schema is used to represent both the comprehensive maps and the student maps described previously.

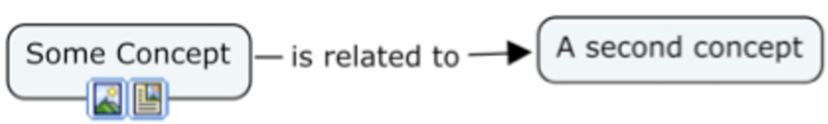

Figure 2 A very simple concept map

1	<?xml version="1.0" encoding="UTF-8"?>
2	<cmap xmlns:dcterms="http://purl.org/dc/terms/" xmlns="http://cmap.ihmc.us/xml/cmap/" xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns:vcard="http://www.w3.org/2001/vcard-rdf/3.0#">
3	<res-meta>…</res-meta>
4	<map width="1002" height="1002">
5	<concept-list>
6	<concept id="1GTFTX8KC-19VH43T-7G" label="A second concept"/>

7	<concept id="1GTFTWV3X-1V61ZKK-6M" label="Some Concept"/>
8	</concept-list>
9	<linking-phrase-list>
10	<linking-phrase id="1GTFTX8L2-15H1SHW-7K" label="is related to"/>
11	</linking-phrase-list>
12	<connection-list>
13	<connection id="1GTFTX8L7-23L9C0K-7P" from-id="1GTFTWV3X-1V61ZKK-6M" to-id="1GTFTX8L2-15H1SHW-7K"/>
14	<connection id="1GTFTX8L8-DDCSTV-7W" from-id="1GTFTX8L2-15H1SHW-7K" to-id="1GTFTX8KC-19VH43T-7G"/>
15	</connection-list>
16	<concept-appearance-list>
17	<concept-appearance id="1GTFTX8KC-19VH43T-7G" x="368" y="133" width="121" height="28"/>
18	<concept-appearance id="1GTFTWV3X-1V61ZKK-6M" x="133" y="136" width="103" height="41"/>
19	</concept-appearance-list>
20	<linking-phrase-appearance-list>
21	<linking-phrase-appearance id="1GTFTX8L2-15H1SHW-7K" x="238" y="136" width="74" height="11"/>
22	</linking-phrase-appearance-list>
23	<connection-appearance-list>
24	<connection-appearance id="1GTFTX8L7-23L9C0K-7P" from-pos="center" to-pos="center"/>
25	<connection-appearance id="1GTFTX8L8-DDCSTV-7W" from-pos="center" to-pos="center"/>
26	</connection-appearance-list>
27	<style-sheet-list>
28	<style-sheet id="_Default_">
29	<map-style background-color="255,255,255,0" image-style="full" image-top-left="0,0"/>
30	<concept-style font-name="Verdana" font-size="12" font-style="plain" font-color="0,0,0,255" text-margin="4" background-color="237,244,246,255" background-image-style="full" border-color="0,0,0,255" border-style="solid" border-thickness="1" border-shape="rounded-rectangle" text-alignment="center" shadow-color="none"/>
31	<linking-phrase-style font-name="Verdana" font-size="12" font-style="plain" font-color="0,0,0,255" text-margin="1" background-color="0,0,255,0" background-image-style="full" border-color="0,0,0,0" border-style="solid" border-thickness="1" border-shape="rectangle" text-alignment="center" shadow-color="none"/>
32	<connection-style color="0,0,0,255" style="solid" thickness="1" type="straight" arrowhead="if-to-concept-and-slopes-up"/>
33	<resource-style font-name="SanSerif" font-size="12" font-style="plain" font-color="0,0,0,255" background-color="192,192,192,255"/>
34	</style-sheet>
35	</style-sheet-list>
36	<extra-graphical-properties-list>
37	<properties-list id="1GTFTVS04-1DS3MHB-6D">
38	<property key="StyleSheetGroup_0" value="//*@!#$%%^&*()() No Grouped StyleSheets @"/>
39	</properties-list>
40	</extra-graphical-properties-list>
41	</map>
42	</cmap>

Table 1 A simple example of the .cxl format XML schema for representing concept maps

An XML Schema for Storing Concept Inventories

The author developed a XML schema that is used to store the questions and answer choices in a concept inventory and also to store correlations between questions in a concept inventory and related elements of an associated concept map. This schema also allows information regarding the level of each question and answer to be represented using Bloom's taxonomy so that student answers can be analyzed based upon the difficulty of the questions and the level of knowledge mastery elicited by the corresponding responses.

Table 2 is an example of how the XML schema was used to represent a question on mechatronics. This question asks students "Mechatronics includes concepts from which of the following disciplines? (check all that apply)" and seven answer choices are given. Line 1 is the standard XML header. Line 2 begins the overall inventory with questions beginning in line 3. The first question starts on line 4. The attribute "BloomByAns" is used to indicate whether the same level of Bloom's taxonomy applies to the entire question or if each answer can have the Bloom's taxonomy level set individually. The text of the question is embedded in the qText tag as shown in line 5. The list of answer choices begins with the <Answers> tag (line 6) and each answer begins with the <Answer> tag. Each answer has attributes to indicate whether or not it is a correct answer and the appropriate level of Bloom's taxonomy corresponding to the answer. The text for each answer is embedded in the tag <AnsText>. For all correct answers there is a <Correlations> tag containing correlations to various corresponding elements in an associate concept map. As is depicted in Lines 17-21 the answer "Computer Engineering" is correlated with two concepts in a concept map labeled "Mechatronics" and "Computer Engineering" and the linking phrase "Is A Synthesis Of" which together establishes the full relationship "Mechatronics is a synthesis of Computer Engineering." Similar correct answers are Electrical Engineering and Mechanical Engineering (lines 23-30 and 39-46, respectively). Table 2 represents only a small portion of the overall concept inventory and each question in the inventory is similarly encapsulated in the XML schema.

1	<?xml version="1.0" encoding="utf-8" standalone="no"?>
2	<Inventory>
3	<Questions>
4	<Question BloomByAns="false">
5	<qText>Mechatronics includes concepts from which of the following disciplines? (check all that apply)</qText>
6	<Answers>
7	<Answer correct="false" Bloom="Knowledge">
8	<AnsText>Aerospace Engineering</AnsText>
9	<Correlations />
10	</Answer>
11	<Answer correct="false" Bloom="Knowledge">
12	<AnsText>Biological Systems Engineering</AnsText>
13	<Correlations />
14	</Answer>
15	<Answer correct="true" Bloom="Knowledge">
16	<AnsText>Computer Engineering</AnsText>
17	<Correlations>
18	<Correlation ConOrRel="Concept" id="1207630738883_517524975_639"> Computer Engineering</Correlation>

```
                <Correlation ConOrRel="Concept" id="1224448487870_351193016_812">
                Mechatronics</Correlation>
                <Correlation ConOrRel="Relationship"
                ConID1="1224448573289_933409053_986"
                ConID2="1224448614495_563632645_1050"
                FromID="1224448487870_351193016_812"
                ToID="1207630738883_517524975_639"
                RelID="1224448573286_1634395768_983">
                Mechatronics Is A Synthesis Of Computer Engineering</Correlation>
            </Correlations>
        </Answer>
        <Answer correct="true" Bloom="Knowledge">
            <AnsText>Electrical Engineering</AnsText>
            <Correlations>
                <Correlation ConOrRel="Concept" id="1207630724177_894092025_612">
                Electrical Engineering</Correlation>
                <Correlation ConOrRel="Concept" id="1224448487870_351193016_812">
                Mechatronics</Correlation>
                <Correlation ConOrRel="Relationship"
                ConID1="1224448573289_933409053_986"
                ConID2="1224448608431_112962706_1038"
                FromID="1224448487870_351193016_812"
                ToID="1207630724177_894092025_612"
                RelID="1224448573286_1634395768_983">
                Mechatronics Is A Synthesis Of Electrical Engineering</Correlation>
            </Correlations>
        </Answer>
        <Answer correct="false" Bloom="Knowledge">
            <AnsText>Environmental Engineering</AnsText>
            <Correlations />
        </Answer>
        <Answer correct="false" Bloom="Knowledge">
            <AnsText>Materials Science Engineering</AnsText>
            <Correlations />
        </Answer>
        <Answer correct="true" Bloom="Knowledge">
            <AnsText>Mechanical Engineering</AnsText>
            <Correlations>
                <Correlation ConOrRel="Concept" id="1207630709310_2117233821_581">
                Mechanical Engineering</Correlation>
                <Correlation ConOrRel="Concept" id="1224448487870_351193016_812">
                Mechatronics</Correlation>
                <Correlation ConOrRel="Relationship"
                ConID1="1224448573289_933409053_986"
                ConID2="1224448573290_1457524147_992"
                FromID="1224448487870_351193016_812"
                ToID="1207630709310_2117233821_581"
                RelID="1224448573286_1634395768_983">
                Mechatronics Is A Synthesis Of Mechanical Engineering</Correlation>
            </Correlations>
        </Answer>
    </Answers>
</Question>
…
```

```
    </Questions>
</Inventory>
```
Table 2 An example of the XML schema used to represent concept inventory questions

Software to Store Concept Inventories

Figure 3 is a screen capture of software created to convert concept inventories into an XML schema. This interface allows for concept inventories to be created from scratch or for previously created inventories to be imported and the text of the questions and answers to be edited. Questions are entered into the interface one at a time with buttons labeled "←Prev Question and "Next Question→" used to move back and forth through the questions. Checkboxes next to each answer are used to indicate which answers are correct. Dropdown boxes are used to select the appropriate level of Bloom's taxonomy corresponding to each answer (or each question if the BloomByAns variable is set to false). The interface allows the entry of up to 20 different answers for each question. The interface allows the user to input the comprehensive map associated with the questions in the inventory for any map stored in .cxl format. Most textboxes are read only unless the user is entering a new question or editing a previously existing question. Figure 3 is a capture of the software after a user has imported a concept inventory on mechatronics and is editing the first question. Notice that several buttons are disabled during editing so that the user cannot move to a different question until editing is completed or cancelled.

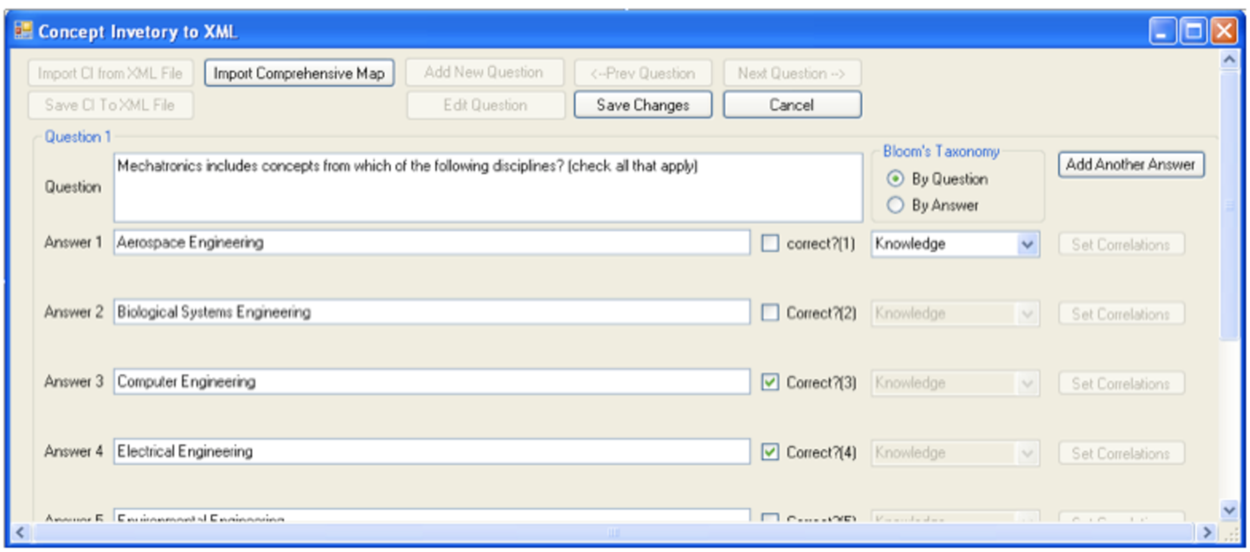

Figure 3 A screen capture of software used to convert a concept inventory into an XML schema

Figure 4 is the dialog box that pops up when the user clicks on the button labeled "Set Correlations." The "Set Correlations" buttons are enabled after the user imports the comprehensive map. This interface allows each answer to be correlated with an unlimited number of concepts and relationships in the comprehensive map. The relationships section allows for the selection of the appropriate linking phrase in context for instance the relationship "Battery Supplies Chemical Energy" involves the concepts "Battery" and "Chemical Energy" and the linking phrase "Supplies."

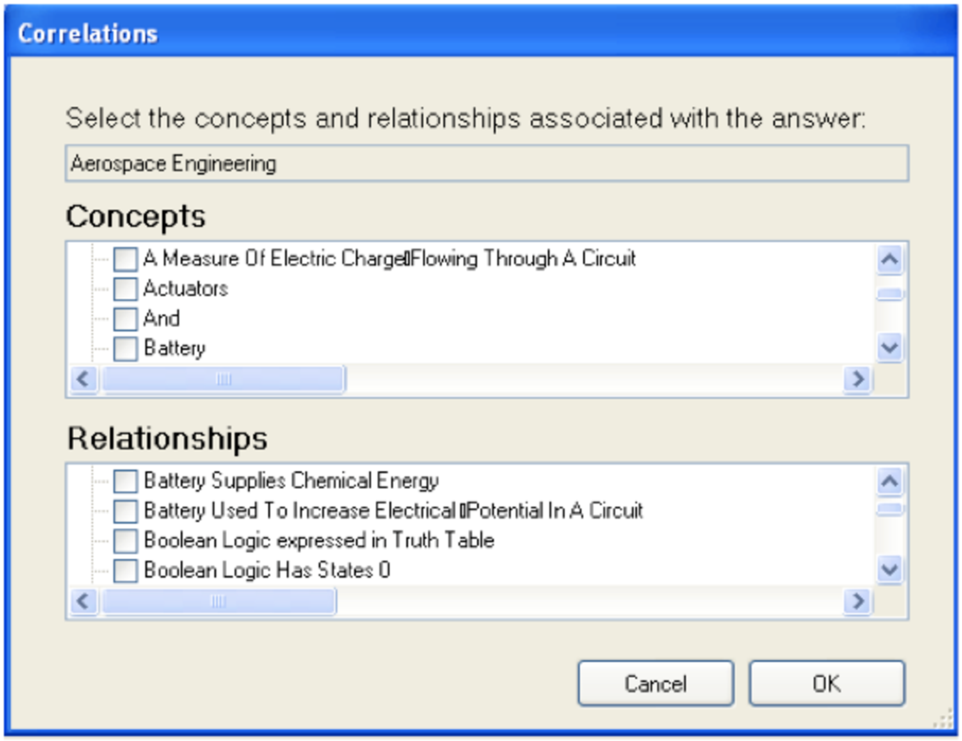

Figure 4 The selection of correlations with the comprehensive map

Software to Generate Student Maps

The software depicted in Figure 5 was used to generate student maps for each student responding to a concept inventory. The software takes seven inputs, the first of which is an XML file containing the concept inventory questions, answers and correlations with a comprehensive map (in the format discussed in the previous section). The second input is a .cxl file containing a related comprehensive map. The third input is a .txt file containing delimited student responses to each of the questions on the concept inventory. The fourth input is the character used as the delimiter in the student data file. The fifth input is the number of identifier entries in the data set used to identify each individual student (such as student ID, name, etc). The sixth input is the number of demographic entries collected when administering the inventory. These demographics entries can include information about ethnicity, name of instructor, age, grade point average, or any other demographic the instructor wants to collect. The final input is the directory where the user would like to store the output student maps.

The software performs string comparison between the answers given by the student and the correct answers in the concept inventory and determines which concepts and relationships from the comprehensive map the students have demonstrated knowledge of based on the correlations between correct answers and comprehensive map elements. Each of these concepts and relationships are included in the student map generated for that student. The demographic information collected is embedded in the metadata in the student map for further analysis. The concepts and relationships are given a color based upon the level of knowledge the student has of the concepts and relationships based upon Bloom's taxonomy [19].

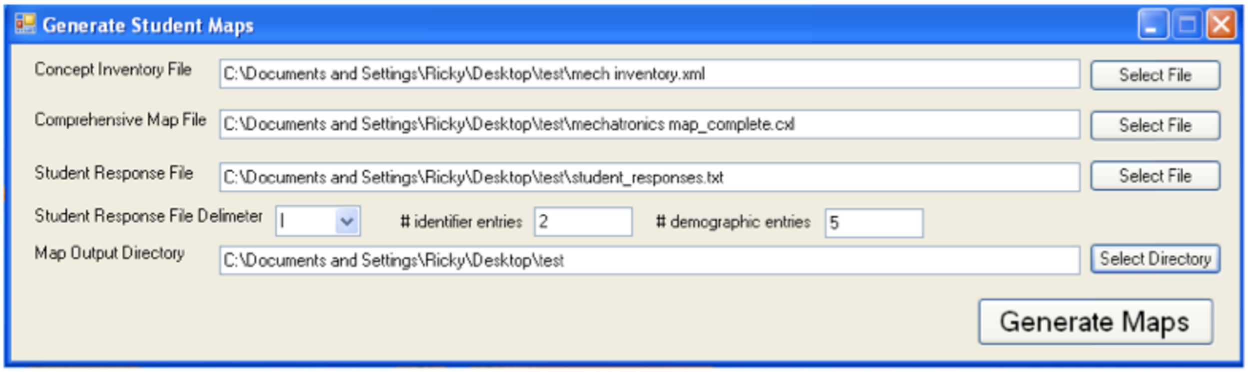

Figure 5 Student Map Generation Software

The maps are of the exact same structure and format as the comprehensive map, but contain coloring based upon the level of knowledge the student has demonstrated and the number of questions the student has answered correctly. Table 3 depicts the set of colors used to represent concepts and relationships in each student map. The ordered triples in Table 3 correspond to the red, green, blue values for the respective colors. The colors of the visible spectrum are correlated with each of the six levels of Bloom's taxonomy. A gradient of colors was selected for each level based upon the percentage of questions the students answered correctly at or below the highest-level question answered correctly. For example if there were five questions relating to a particular concept, two at the Knowledge level, two at the Understanding level, and one at the Application level, and a student answered all but the Application level question correctly then the corresponding concept node would appear in a dark yellow color in the student map. If another student answered only one of the Knowledge level questions correct then that concept node would appear in a light red color in their map. If a student answers no questions corresponding to a particular concept or relationship then the corresponding concept(s) and/or linking phrase(s) is(are) absent from their student map. Equation 1 is used to compute the correct RGB value for the color representative of each students understanding of the corresponding concepts and relationships. R_{minL} and R_{maxL}, G_{minL} and G_{maxL}, and B_{minL} and B_{maxL} correspond to the beginning and end of the range of the red, green, and blue coordinates, respectively, for the level, L, determined by the highest level question the student answered correctly that corresponded with the concept or relationship and depicted in Table 3. C indicates the total number of correct answers the student gave at any level that were correlated with the associated concept or relationship. A_L indicates the total number of possible correct answers at or below level L in the inventory that correspond to a particular concept or relationship.

$$Color_E = \left(R_{\min_L} + \frac{C(R_{\max_L} - R_{\min_L})}{A_L},\quad G_{\min_L} + \frac{C(G_{\max_L} - G_{\min_L})}{A_L},\quad B_{\min_L} + \frac{C(B_{\max_L} - B_{\min_L})}{A_L}, \right)$$

Equation 1 Formula for RGB values based upon correct answers to corresponding concept inventory questions.

		Percentage of Questions at or Below the Top Level Answered Correctly	
		>0	100
Level	Knowledge	(255,160,160)	(255,0,0)
	Understanding	(255,208,80)	(255,128,0)
	Application	(255,255,160)	(255,255,0)
	Analysis	(200,255,200)	(0,255,0)
	Synthesis	(200,200,255)	(0,0,255)
	Evaluation	(255,128,255)	(127,0,127)

Table 3 The table of colors used to represent each concept or relationship in each student map based upon the quantity and level of the questions answered correctly

Software to Generate Aggregate Maps

In order to perform more detailed analysis of the impact of the curriculum on groups of students, software was developed to take in a set of student maps and generate an aggregate map as a result. This process counts each of the concepts and relationships in each student map and reports the percentage of students that showed knowledge of each in a concept map. The structure of the aggregate map is the same as that of the comprehensive map. Consider the following simple example based upon three student maps. In these student maps the concepts are labeled generically with numbers and the relationships are labeled with letters in order to showcase how this method may be used with student maps from any discipline.

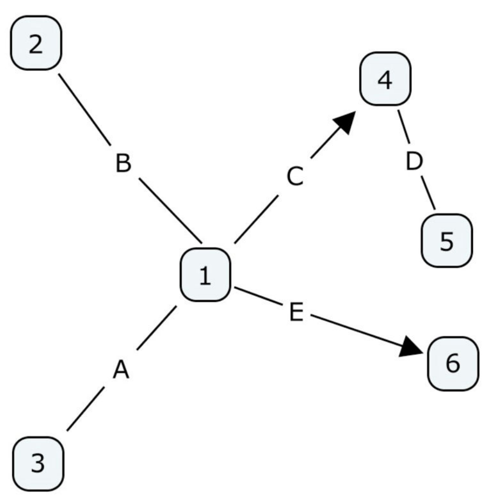

Figure 6 One student map

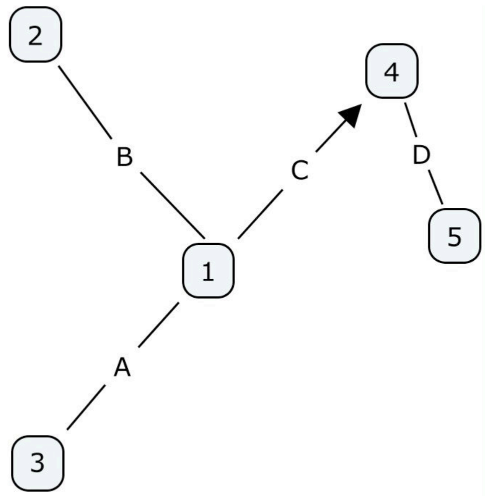

Figure 7 A second student map

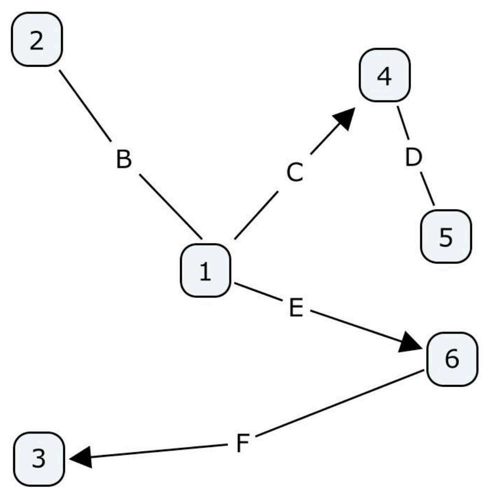

Figure 8 A third student map

The aggregate map for the three student maps in Figure 6, Figure 7, and Figure 8 is depicted in Figure 9. Aggregate maps can be formed for all students in a particular class or based on various demographics. In this way instructors can examine the difference in conceptual understanding of high-performing students and low-performing students. Instructors can also identify if there are any biases in the curriculum based on factors such as gender or race. Aggregate maps may be formed for students from different sections of a course in order to compare outcomes-based performance of different instructional approaches to the same curriculum. Similar comparisons may be done over time to see how instructors are improving in their effectiveness from year-to-year.

A screen capture of software designed to form aggregate maps from groups of student maps is depicted in Figure 10. This software takes as input a comprehensive map file in .cxl format and a directory containing a set of student maps. The software forms maps based upon either all of the student maps in the directory or based upon maps containing selected demographic information.

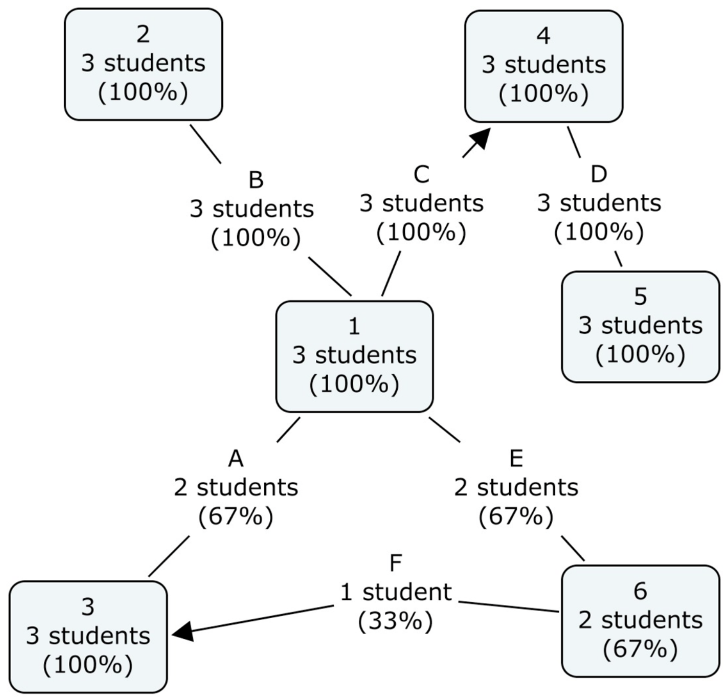

Figure 9 Aggregate map for the three student maps given in Figure 6-Figure 8

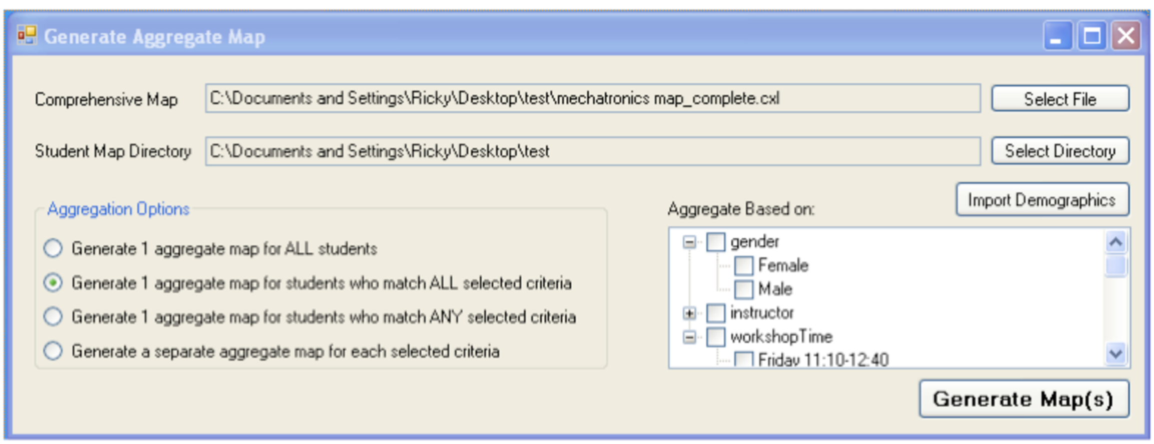

Figure 10 Aggregate map generation software

Division of Responsibilities

The following table outlines the responsibilities of the instructor, students, and software when this system is deployed.

Instructor	Student	Software
Analyze course content and develop appropriate comprehensive concept maps. Develop appropriate multiple-choice or multiple-answer	Learn course material and respond to multiple-choice or multiple-answer questions.	Parse student responses to inventory questions. Check student responses for correctness

questions to evaluate student understanding of course concepts. Couple the various questions in the inventory with the various portions of the comprehensive map and ensure full coverage of the map with the set of questions used. Classify questions and answers based upon the various levels of Bloom's taxonomy. Deploy questions and answer choices to students and establish a method for data collection, preferably online or via some other electronic means.		Generate a student map for each student in the course representative of that student's knowledge of course concepts. Parse sets of student maps to form aggregate maps for groups of students.

System Deployment

A custom concept inventory was developed to evaluate students' understanding of the underlying concepts and relationships in a mechatronics learning module that is part of a first-semester, first-year introductory engineering course at Virginia Tech. An instructor made a thorough analysis of all of the instructional material involved in the unit including an online lecture, a homework assignment, and a hands-on laboratory exercise to develop a comprehensive list of every concept and relationship covered by the unit. Questions were then developed to evaluate student understanding of the underlying concepts through an online survey. These were deployed in the first semester of development as open-ended, free response questions in order to determine what students knew about underlying electrical and mechanical principles including voltage, torque, friction, gears, motors, etc. Student responses in one semester were then used to drive the development of multiple-choice and multiple-answer questions for deployment in the following semester. These multiple-choice and multiple-answer questions were then deployed to approximately 1400 students enrolled in this large course in Fall 2008. As a proof of concept of the methods and software, a similar approach was used to assess student understanding of concepts and relationships in a similar course unit on autonomous vehicles in a second-semester, first-year engineering course designed for students in electrical engineering, computer engineering, and computer science.

As of the deployment of the online survey, the various software packages described herein for processing of the survey data were still under development, so unfortunately that batch of students did not receive feedback in the form of student concept maps. In future semesters the authors intend to collect and process data and return student concept maps to students immediately in order to illustrate their mastery and weaknesses relative to the entire body of knowledge.

Conclusions

This paper has presented a software-based analysis system for evaluating student understanding using concept maps. The software has been tested using two different learning modules in freshman engineering courses with over 1500 students at Virginia Tech. The software is designed to provide a generic interface for the entry of concept inventories, concept maps, and evaluation of student answers. This analysis technique has implications for outcomes based instructor evaluation, student evaluation, and also accreditation.

By presenting instructors with detailed maps of what each student has learned through various course units, instructors can pinpoint which concepts should be better addressed in the future in order to compensate for any misconceptions identified in the student maps. Aggregate maps become useful when trying to get the big picture of the overall class and individual student maps are useful in order to help students on an individual basis, particularly during office hours or tutoring sessions. Student maps could also serve as a basis for personalized tutoring systems tailor to each individual’s strengths and weaknesses as identified by the concept inventory.

Accreditation boards could establish universally accepted comprehensive maps and judge the quality of a program based upon the student maps held by students at various phases of the curriculum in order to simplify the process of evaluating the outcomes of the curriculum.

The development of appropriate and comprehensive concept maps and corresponding inventories is a bit cumbersome, but once such development is completed then the inventory may be repeatedly deployed to many students. The goal of this project is to develop enough comprehensive maps and inventories that this software is useful for a variety of applications at a variety of universities.

Future Work

The system currently only allows for the parsing of responses to multiple-choice or multiple-answer questions. A useful extension to this tool would be the incorporation of natural language processing techniques in order to process responses from students in a more narrative form and to be able to analyze inked responses to draw meaning from pen strokes in order to allow more free-formed answers to be processed. Further, the system currently only generates maps representative of the subset of the comprehensive map that students demonstrated mastery of. A useful extension of this software would be to include the ability to graphically depict misconceptions also.

The system was deployed to many students and their data were analyzed on a post-hoc basis after the course had completed. This gave the instructors great insight into what students had learned, but unfortunately took the students out of the feedback portion of the loop in these situations. In the future the authors intend to analyze student responses in the middle of the course and present that feedback to some students while not presenting it to a control group in order to determine if the presentation of such feedback yields an increase in student learning.

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