AC 2009-1913: A PARADIGM FOR COMPREHENSIVE CONCEPT MAP-BASED MODELING OF STUDENT KNOWLEDGE

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A Paradigm for Comprehensive Concept Map-Based Modeling of Student Knowledge

Abstract

The current method of modeling the level of understanding students have of course content with a single letter grade is primitive at best. The simplification of weeks of learning into a single character representation does little to convey what a student ultimately knows. Two students who receive the same grade in a course may, and often do, have a very different level of mastery of various course concepts. This paper presents a new paradigm for knowledge modeling and assessment based on concept maps and concept inventories.

Under this assessment method, student maps are generated to graphically depict a comprehensive model of student understanding of course concepts. This assessment paradigm begins by creating a comprehensive concept map that depicts each of the relevant concepts and relationships within the topic area being studied. Based upon a concept-inventory-driven analysis of student knowledge, a concept map representing the subset of the comprehensive map that students have mastered is generated as a representation of each student's knowledge.

This paper presents an example of how such an assessment paradigm has been implemented in a mechatronics course unit in a large freshman engineering course. This course unit introduces students to many concepts from electrical, computer, and mechanical engineering. The unit includes an online lecture and a hands-on, lab-based activity in which students build a simple mobile robot. Over 1400 students participated in this course unit in Fall 2008. While the scope of this work is within a single course unit, this paper describes how such modeling can be done on a large scale to represent student knowledge gains in an entire course or even an entire degree program.

The methods used for building the comprehensive concept map and an appropriate concept inventory are described. The software developed to generate student maps based on responses to a concept inventory is also discussed. Many applications of this paradigm are described including the use of such assessment methods to augment university admissions data, the ability to replace or augment transcripts and resumes with detailed student maps, the development of college rankings based on student learning outcomes, and objective faculty teaching evaluation based on student learning outcomes.

Introduction

Much work has been done in attempting to discover how people learn[1] and the processes involved in general cognition[2]. Concept maps have become more widely used in education as both tools for facilitating student learning[3] and for academic research and knowledge modeling[4]. Concept maps provide a general structure for outlining conceptual knowledge and relationships. Concept maps take on the form of directed graphs where nodes on the graph indicate concepts and the edges of the graph indicate the relationships between those concepts. In Figure 1 a concept map is used to depict the features and utility of concept maps as a modeling tool. Concept maps may be used by students to outline their own understanding of

educational material and may also be used by educators in order to layout a framework for the information they wish to impart to their students. Through this paper the author will introduce a framework for collaboratively mapping concepts and relationships using concept maps and a strategy for linking an appropriate concept inventory with a concept map to enable concept-based evaluation of student understanding.

Figure 1 A concept map about concept maps[5]

A Brief History of Concept Maps and Concept Inventories

Concept maps were developed by Joseph Novak in 1972[5]. 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. Concept maps made it possible to graphically depict how children understood various concepts and their relationship with other concepts. Novak's work was based on the cognitive psychology work of David Ausubel in the 1960s and 70s[6-8]. 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. Through the use of concept maps it is possible to trace the expansion and refinement of a student's cognitive structure over time.

Concept inventories were developed out of a need to assess student understanding of the fundamental concepts included in a discipline. Concept inventories are typically multiple-choice assessments that are used to check basic understanding of underlying principles without

burdening the test-taker with the complexity of higher ordered mathematics or other confounding factors found in most assessments of knowledge. The first concept inventory, the Force Concept Inventory (FCI), was developed by Hestenes, Wells, and Swackhamer in 1992[9]. This assessment tested students' basic understanding of kinematics that should be attained through an introductory physics course at any level. The results of the inventory showed the disparity between Newtonian physics concepts and the understanding of physics concepts people have developed based on their previous life experience and through common sense and intuition. The results of assessments using the FCI are consistent with Ausubel's theory of knowledge assimilation as they showcase the difficulty students have in inserting new knowledge into a flawed preconceived notion of physics principles.

Current Knowledge Representation Strategies

Currently most educational institutions represent student knowledge in the form of academic transcripts, which contain a list of all the courses the student has taken and the grades the student has earned in each course. This list of courses and grades earned is further condensed into a grade point average which is the most fundamental data point used by students to convey their academic aptitude to others. The problem with such a condensed representation of student knowledge is that it contains significant confounding factors. If two students receive the same grade in a course, do they both have the same level of understanding of each of the concepts relevant to that course? Most likely not. If two instructors teach the same course, do they both emphasize all of the concepts in the same manner? Probably not. If two students happen to have the same grade point average, can they be considered to be equally knowledgeable about all things? Certainly not.

Once students leave the confines of a classroom there is little concern for the grade they achieved as a student and more concern for their understanding of the knowledge they gained through the academic learning process. It becomes important then to delineate conceptual understanding of each student in an intuitive manner. This paper presents a method for utilizing concept maps as a visual representation of the fundamental understanding people have of the concepts and relationships underlying a discipline. It is important to not only represent that students have knowledge of a concept or not, but also to showcase the level of understanding of that knowledge. Modeling strategies like Bloom's taxonomy[10] become helpful to showcase the depth of understanding students have and their ability to apply knowledge in a practical manner.

Overall Strategy for Student Knowledge Representation

Education can be modeled as a closed-loop feedback controller. As is depicted in Figure 2, the first step in education is to determine the knowledge intended to be conveyed to students. Once it has been determined what will be conveyed to students, instructors must determine how they will convey that knowledge. The students themselves are the system and assessment tools serve as sensors to determine the system response. The difference between the desired knowledge and the measured knowledge that was actually imparted serves as feedback regarding the success or failure of the instructional process to impart the desired knowledge. Any discrepancy between desired knowledge and measured knowledge serves as a basis for improving the curriculum in an attempt to more adequately convey such information in the future.

Figure 2 Modeling education as a closed-loop feedback controller

The scope of the method described in this paper is the development of models of knowledge and appropriate assessment so the desired knowledge may be directly compared with the measured student knowledge at a conceptual level. Figure 3 depicts the process of developing a comprehensive knowledge map and an appropriate concept inventory to measure each student's knowledge of those concepts. The following two sections discuss methods for concept map and concept inventory development.

Figure 3 The development of a comprehensive knowledge map and an appropriately related concept inventory

Development of a Comprehensive Knowledge Map

The development of a comprehensive knowledge map is fundamental to this assessment strategy. By developing a comprehensive map of each of the concepts and relationships the curriculum is

driven to include the appropriate concepts and relationships and assessment techniques can be developed to evaluate student understanding of each concept. As is depicted in Figure 3, this process begins by convening a panel of experts to develop the map. These experts draw from their own understanding of the topic in question and also pull relevant information from the literature in order to map out each of the appropriate concepts and how they relate to one another. The development of collaborative maps has been widely studied and it has been determined that collaboratively developed maps are more representative and accurate depictions of a discipline than concept maps developed solely by one person individually[11]. This mapping strategy may be applied to virtually any field, not just engineering fields. A variety of software packages are available to allow for such mapping to take place[12, 13].

Development of a Concept Inventory

Once the concepts have been mapped appropriately in a concept map, an assessment strategy must be developed in order to determine the portion of the conceptual information the students have mastered. Concept inventories provide an ideal format for assessing conceptual understanding. Each question in a concept inventory is designed to be multiple-choice which allows for rapid automated scoring. The questions in a concept inventory are designed to assess conceptual understanding without the influence of confounding factors such as rigorous arithmetic computation. It is sometimes difficult to determine on traditional examinations if students missed questions because they did not understand the underlying concepts or if they simply made a computation error. This is particularly true on multiple-choice assessment rather than free response questions. The assessment methods in concept inventories reduce this indeterminate evaluation and showcase at the conceptual level what students do and do not know.

A concept inventory should have questions that evaluate understanding of each of the underlying concepts. In this manner each of the questions in a concept inventory is directly tied to a node or edge in the corresponding concept map. It is also important to create some redundancy in the development of a concept inventory so it can be stated confidently that students do or do not understand a particular concept based upon several data points. It is possible, and often appropriate, to connect one question with several nodes and edges in the concept map, but it is important to not introduce confounding factors into the assessment process due to undue complexity in the questions on the concept inventory. Different types of questions should also be incorporated into a concept inventory in order to determine a student's level of understanding within Bloom's taxonomy. In [14] example questions are described to assess the various levels of Bloom's taxonomy in computer science, but a similar approach could be done in many disciplines.

Generation of Student Maps

Once the course content has been determined and appropriately mapped and a concept inventory has been developed to assess student understanding of the concepts it is possible to use the concept inventory to evaluate student understanding. Each answer students supply to the questions on the concept inventory gives insight into their understanding or lack of understanding of the corresponding concept. The linking of questions in the concept inventory

to various levels in Bloom's taxonomy allows for a student map to depict the corresponding level of understanding each student has for each concept. In Figure 4 the method of generating student knowledge maps based upon answers to a concept inventory is illustrated. Students think about what they have learned and answer questions in a computer-based concept inventory. Software developed by the first author is deployed to take in students' responses to the concept inventory and to generate a set of maps containing an individual representation of each student's knowledge. The student maps generated by this process are all subsets of the comprehensive map. Any concepts and relationships that the student does not demonstrate an understanding of are removed from the student map.

Figure 4 Generating student knowledge maps based upon answers to a concept inventory

Implementation in a Course Unit

This method of knowledge representation and evaluation has been successfully implemented in a course unit that is part of a large first-semester freshman engineering course. The course unit chosen for deployment of this strategy focuses on mechatronics and introduces students to mechanics, electronics, and Boolean logic in an interdisciplinary manner. The course unit includes an online lecture, a homework assignment, and a hands-on activity where students build a simple mobile robot.

The authors iteratively developed the comprehensive knowledge map by studying the content of the online lecture and analyzing each portion of the instructions for the hands-on activity. Each time a new concept was introduced it was written down and then once a complete listing of concepts was developed all the concepts were integrated into the comprehensive map depicted in Figure 5. A corresponding concept inventory was developed to assess student understanding of each of the underlying concepts and relationships. In Spring 2008 a pilot of the assessment was deployed and no answers were provided to the questions on the concept inventory. The answers collected were all free response from 108 students. This method of data collection allowed the concept inventory to be developed using actual student responses as the correct and incorrect choices on the concept inventory. A full deployment of the concept inventory was done in Fall 2008 and data from 1402 students was collected. The data is currently being processed to generate the individual student maps and to perform aggregate analysis.

Student Mapping Software

The software developed by the first author takes in a list of questions and answer choices, an answer key, and a set of student responses and generates a map for each student. This software requires a correlation file to be imported in order to showcase which nodes and edges on the comprehensive map correspond to each question in the concept inventory. The comprehensive map is also input into the program in an XML file and serves as a basis for the student maps. Using all this information, a batch-wise procedure can be run to process each of the student responses and to populate the student maps appropriately. The various levels of Bloom's taxonomy are showcased in the student maps with the use of color with different colors representing different levels of student understanding. The first author is currently developing software to generate aggregate maps for more thorough demographics-based assessment.

Uses of Student Concept Maps

Student concept maps can be used for a variety of purposes. A student map can serve as a supplement to a resume or transcript in order to showcase at the conceptual level what a person does and does not know. In this way a potential employer can make a more informed decision about the applicants they hire and can know that their employees possess the requisite knowledge rather than having to estimate an applicant's knowledge based upon the coursework indicated on their transcripts.

Figure 5 The comprehensive concept map developed for a mechatronics unit in a first-semester engineering course

Sets of student concept maps may be combined to form an aggregate map in order to perform analysis based on key demographics. An instructor may be interested in determining if there is a correlation between understanding of certain concepts and various demographics including gender, race, class standing, age, or grade point average. Through aggregate assessment one could compare the knowledge maps of students with high grade averages to maps of students with low grade averages in order to determine any deficiencies and to perhaps isolate the causation of those deficiencies.

Student maps can be used to assign grades in a course. Rather than assigning weights to various assignments and giving grades on each assignment, an instructor could assign weights to each topic and then grade students based upon their understanding of different course concepts associated with that topic. This assessment method is independent of the assignments making grading become outcomes based rather than means based.

The development of agreed upon concept inventories for engineering courses and appropriate evaluations has potential to greatly simplify the accreditation process. Rather than having to develop a large bank of assessment data regarding the objectives in a course and the means used to attain those objectives, an instructor could simply produce a set of student maps to showcase the concept students learned when they completed a course.

Aggregate student maps also allow for objective faculty evaluation and opportunities for collaboration. If it is determined that one instructor does not do a good job of conveying a particular concept to his or her students then they can collaborate with other instructors to determine how they can improve their teaching of that concept. Outcomes-based teaching evaluations are much more objective than standard teaching evaluations that showcase primarily opinions rather than facts about the effectiveness of a teacher in conveying knowledge.

College admissions officers are faced with the daunting task of comparing students who have been assessed under very different academic assessment structures. Different school systems use different grading scales and it is impossible to simply compare one grade point average to another to objectively evaluate student aptitude. Different courses with the same name may also be taught with very different rigor in different schools. If a universally accepted concept-map based assessment strategy were developed then a thorough analysis of student concept maps would indicate in an objective manner what students do and do not know. This same method could be used to analyze the performance of students at one university relative to the performance of students at another university in order to do an outcomes based assessment.

Conclusions

It is necessary to remove some ambiguity from the current method of representing student knowledge using transcripts that only depict that a student was enrolled in a course and earned a certain letter grade. In this paper a method for assessing student knowledge based on responses to concept inventories was described. Using concept maps it is possible to graphically depict the set of knowledge each student has and this can be used in a variety of applications. While this method requires a large amount of work in analyzing knowledge in order to establish an

appropriate comprehensive map, this method does provide a much clearer insight into the fundamental understanding students gain based upon their enrollment in assorted courses.

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