Understanding What Students Understand: Knowledge Structures of Computer Networking Students

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Abstract

It is important for instructors to recognize how students organize and relate ideas to each other, allowing them to identify student misconceptions. Students must learn not just concepts, but how different concepts in a domain fit together. In the field of computer networking, little is known about how students conceptualize the domain, or how that changes over time. Using a technique of rating similarity between words, this paper demonstrates the change in students' models of computer networking over time, and discusses how the technique might be used to evaluate changes in knowledge structure in other disciplines.

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Assessment is as much a hot-button issue in Career and Technical Education (CTE) as it is in the rest of education. Testing is now a major part of accountability under both the No Child Left Behind and Carl D. Perkins Career and Technical Education Acts. In addition, research on school improvement has demonstrated that schools and teachers who use data to continually monitor student progress are likely to improve (Waits et al, 2006). This has all resulted in a variety of assessment options in CTE ranging from large-scale online multiple choice exams to portfolio assessment systems to practical, hands-on assessments. Different assessments address different learning outcomes. These outcomes can generally be classified as cognitive, skills-based, and affective (Kraiger, Ford & Salas, 1993). Within cognitive outcomes, learning can be classified as verbal knowledge, knowledge organization, or cognitive strategies. Despite the array of assessment tools available, very few allow for the observation of how students organize knowledge.

It is important for instructors to recognize how students organize and relate ideas to each other, allowing them to identify student misconceptions. Students must learn not just concepts but how different concepts in a domain fit together (Ausubel, 1968). Just as a student may understand how to do a calculation without understanding why, a student may understand one component of a domain without understanding how it fits in to the domain as a whole (Borgen & Manu, 2002). In fact, students build mental models or representations of knowledge in a particular area. However, Resnick (1987) concluded that without explicit assistance in connecting ideas, people do not usually learn concepts simply by building up pieces of knowledge. In fact, they may come up with their own idiosyncratic understandings of how ideas relate to each other (Bransford, Brown, & Codking, 2000). One way to visualize these models is through the use of concept maps.

Concept maps are visual representations of how concepts are related to each other. Each concept is a node, connected to other related concepts. The maps theoretically represent the knowledge structures of the person who is drawing them. Concept maps can be used as a learning strategy, an instructional strategy, a strategy for curriculum planning, and/or a means of assessment (Novak, 1990). It is clear that visual inspection of concept maps can lead to an understanding of students' misconceptions; one can see where there are links that should not be present and where there are not links that should be present. However, visual examination limits the number of students who can validly be studied.

One technique has emerged that may allow for both the investigation of large numbers of students and location of specific misconceptions - the use of numerical judgments of similarity or closeness among a set of concepts (Kraiger, Ford, & Salas, 1993). These ratings can then be converted into concept maps and their structures assessed using procedures in the Pathfinder network program (Schvaneveldt, 1990). The Pathfinder network scaling algorithm generates a network representation of the structure of the similarity ratings submitted for analysis. This representation contains concepts represented by nodes and links between nodes to demonstrate relationships; this is essentially a concept map without labels on the links. The resulting map can be compared to an expert/ instructor's map and a measure of similarity obtained based on the number of common links. In addition, ratings can be combined to produce "average" networks across individuals.

Conceptions About Computer Networking

Computer networks have grown exponentially, with over 1 billion people worldwide using the internet, a growth of over 200% just from 2000 to 2006 (Internet World Stats, 2006). This has resulted in large growth in the need for people to design, implement, and maintain networks, and a concomitant increase in the numbers of students taking networking courses. To date, over 1.3 million students have completed the first class in the Cisco Certified Network Associate (CCNA) curriculum.

Given these numbers, it seems important to begin to understand how students learn networking. In addition, it would be advantageous to understand the knowledge structures of networking experts. This paper is a preliminary investigation to determine whether the Pathfinder procedures can be used to determine how entering networking students and their instructors conceptualize the main ideas in computer networking, and how the students' networks change over the course of instruction.

Method

Participants

Six teachers at 6 different schools teaching the Cisco Networking Academy curricula participated in the study. Three teachers taught in high schools and three taught in community or technical colleges. Teachers had previously indicated interest in participating in research on teaching and learning and volunteered for participation in response to an email solicitation describing the study. They averaged three years of experience both on working on production networks and teaching in the Cisco Networking Academy.

A total of 78 students participated in the study. Class sizes ranged from 6 to 24 students with a median of 13 students. Students were asked to rate their knowledge about networking; 31% indicated they did not know much about networking, 50% indicated that they knew a little about networking, 17% indicated they knew quite a bit about networking, and 2% indicated they know a lot about networking.

This research was completed in the context of the Cisco Networking Academy, a global program in which information technology is taught in high schools, community colleges, and universities via a blended program with face-to-face classroom instruction, an online curriculum, and online assessments. For purposes of this initial study, participants all came from U.S. schools using the English curriculum. All classes were CCNA (Cisco Certified Network Associate) 1 classes, which is the first in a set of 4 classes which prepare students to take the CCNA Certification exam, as well as to obtain networking jobs. Instructors for the classes are regular faculty at the schools and students take the courses as part of their regular course load.

Materials and Procedure

The initial step in the study was to identify the salient terms to be rated to create the knowledge network. This was done via a review of the curriculum, including the stated objectives and important terms to generate a list of eight items that covered course concepts: router, switch, IP Addressing, subnetting, fiber optic, UTP, Ethernet, MAC Address.

Instructors and students used a computer program to rate every possible pairwise combination of the terms on a 10 point relatedness scale (1 = unrelated; 10 = highly related). The pairs were presented in random order for rating. Raters were instructed to give quick judgments of relatedness rather than lengthy, deliberate ones. Both instructors and students completed the ratings at the beginning of the course, prior to any instruction on the topics to be rated.[1] Following the semester-long course, students completed the ratings for a second time so the comparison to both their previous network and the network of their instructors could be made.

Pathfinder Procedure

The Pathfinder network algorithm (Schvaneveldt, 1990) was used to generate a network representing each student and instructor's organization of knowledge. Two parameters (q and r) need to be determined in the Pathfinder program to generate networks. In this case, the parameters used to compute the network were set at r = infinity and q = n-1, where n refers to the number of terms in the data. The r parameter was chosen to match the ordinal properties of the data, and the q parameter was chosen in order to generate the sparsest network possible from the given data. These are the accepted settings for data of the type in this study (Gomez et al., 1996; Schvaneveldt, 1990). In general, links are made between concepts (nodes) when the similarity between those nodes is greater than or equal to the total similarity of any other path having no more than q links.

The Pathfinder program averaged the data of instructors and students to obtain consensus networks. These networks can then be compared to each other. The similarity between the two networks is computed as the number of links in common divided by uncommon links. (The number of uncommon links is the total number of links in both graphs minus the number of common links.) Two identical networks will yield a similarity of 1 and two networks that share no links will have a similarity of 0. The

Pathfinder program also determines the probability of obtaining the observed number of links in common or more by chance from the hypergeometric probability distribution. Schvaneveldt (2007) suggests this can be used as a statistical test of similarity; in general we would want there to be less than a .05 probability of the networks sharing these paths by chance in order to say the two networks were statistically similar. This is a test in which the null hypothesis is that the two networks are different. If the probability of sharing links by chance is less than .05, then the null hypothesis is rejected and we say the two networks are statistically similar. This is a different test than traditional hypothesis test in which the null hypothesis is that two groups of data are the same and rejecting the null hypothesis indicates they are significantly different.

Results

The instructor network is displayed in figure 1. Interestingly, the instructors' network came out very linearly. However, the words are clearly organized based on the OSI model. The OSI model is an abstract model of networking that divides a networking system into seven "layers." The first layer is the physical layer, which represents all the electrical and physical specifications. Fiber optic and UTP cable are part of this layer. Layer 2 is the data link layer, which provides the means to transfer data on the network. The Ethernet is the best example of this and switches and MAC Addresses are also associated with this layer. Layer 3 is the network layer, which allows data of different lengths to move across networks. Routers, IP Addresses, and subnetting are all associated with this layer.

The student pre-instruction network is displayed in figure 2. The Pathfinder program provides a statistical test to determine the probability that two networks would share the same number of nodes by chance. The two networks share 22% of their links, and it is likely that a number this small could be shared by chance ($p = .22$), indicating the students' network is significantly different than the instructors' network. Examination of the students' network shows that they clearly lack this method of organizing their knowledge. Although formal knowledge of the OSI model would not be expected of incoming students, it is clear that they do not have a general conceptual understanding of how these concepts relate to each other to make up a network. The students' network also identifies specific areas where students have made incorrect links. For example, MAC addresses are not closely related to IP addresses. Students likely had not heard of one or both and linked them based on the fact that both had "address" in them. There should be links between IP addressing and routers and MAC addresses and switches.

Figure 3 displays the students' post-instruction network diagrams. This diagram shares 40% of its links with the instructor network and it is less likely that this number would be shared by chance ($p = .04$). Although at first the changes from pre-instruction to post-instruction do not appear great, inspection reveals that students seem to have made changes indicative of more organized thinking about networks. MAC addresses are now linked to switches, forming a layer two section. IP Addresses are now linked to routers.

Discussion

It is important for instructors to understand how their students organize knowledge. In order to examine these patterns across a group of students, ratings of important concepts were obtained and resulting Pathfinder networks were calculated. These provide both visual and statistical evidence of student and instructor conceptualizations of content. In this study, an average student network was compared to an instructor network prior to instruction. As expected, the novice students' networks were different than the instructors, and specific areas of difference could be identified. Examination of the instructors' networks also confirmed that they view the content of the course based on the theoretical model of networking. The student networks were then examined after instruction to determine whether misconceptions had been eliminated, and how similar their thinking was to their instructors. This analysis revealed changes in knowledge organization which made their networks more similar to that of their instructors. In summary, the study demonstrated both misconceptions common across six computer networking classes and correction of those misconceptions over exposure to the curriculum.

Limitations

A major limitation of this research is the limited number of concepts rated. Due to the fact that each new concept must be rated against every other concept, adding concepts greatly increases the number of ratings that must be completed. It was found in pilot testing that having a large number of ratings resulted in more participants selecting the same rating number for all pairs. However, using a limited number of concepts means that less information can be gained from examination of the networks. One way to address this would be to limit the scope of the curriculum covered. In other words, rather than surveying an entire course, as this research did, creating networks for single chapters as they are taught will provide more detail about students' understanding of particular chapters.

Directions for Future Research

Given that this study suggests that the Pathfinder technique can show change in knowledge organization as a result of instruction, it would now be instructive to examine the effect of various instructional interventions on students' networks. This study made no attempt to identify the methods of instruction used by teachers in the participating classrooms. Future research might examine the utility of various instructional methods in influencing students' conceptualizations.

Application to Other Disciplines

This paper demonstrates the usefulness of the Pathfinder technique for examining the knowledge structures of technical students and the change in this structure over time. This same technique could be used in other disciplines. The advantages of having students make numerical judgments, as opposed to drawing concept maps, are: 1) it allows for both examination of individual responses and consolidation across multiple students, resulting in easier analysis of the understanding of a class or group of classes, and 2) it provides statistical evidence that can be used to quantitatively demonstrate change in knowledge organization over time as well as the more qualitative understanding that can be gained from examination of the networks themselves. This opens up this technique for both pre-assessment, formative assessment, and summative assessment of knowledge organization in a variety of disciplines.

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Footnotes

[1]Results from the pre-assessment were part of a larger pre-assessment project previously reported in DiCerbo, K. (2007). Knowledge Structures of Entering Computer Networking Students and Their Instructors. *Journal of Information Technology Education, 6*, 263-277.

Figure 1. Instructors' Pathfinder Network

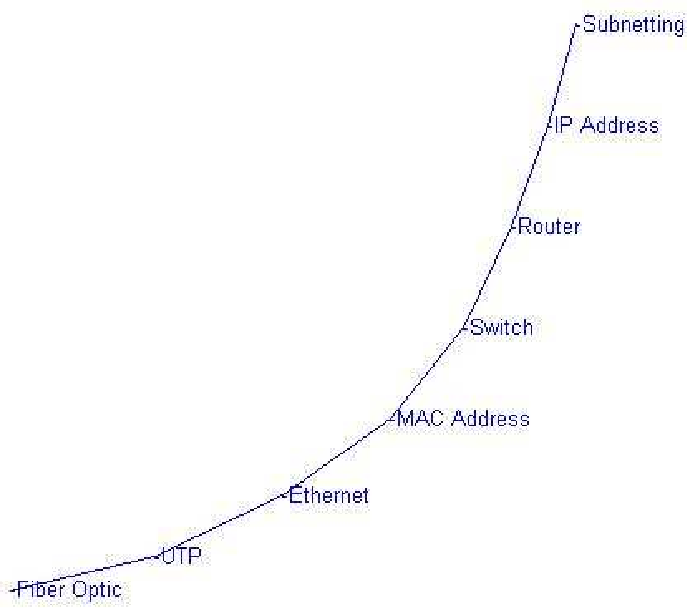

Figure 2. Students' Pathfinder Network Prior to Instruction

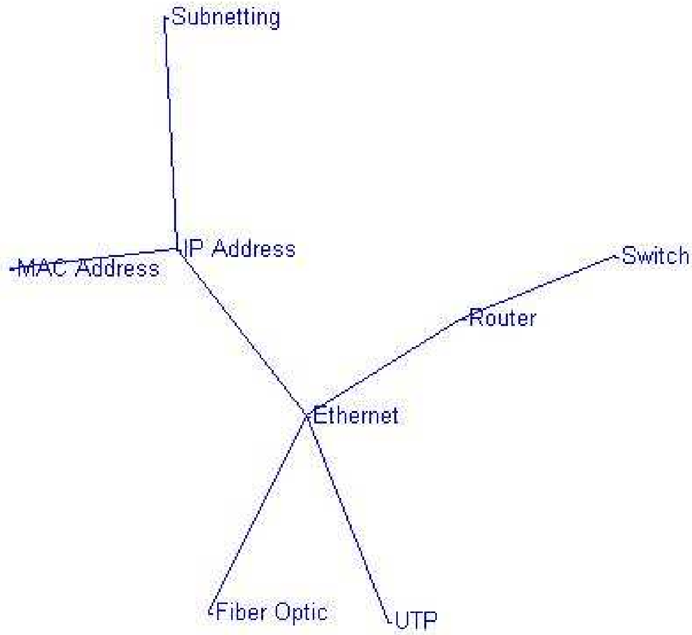

Figure 3. Students' Pathfinder Network After Instruction