Do engineering students learn concepts better when required to link them?

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Structured abstract

BACKGROUND
Concept maps graphically depict how the concepts in a subject area (nodes in the graph) are related through links between the nodes. They can aid meaningful learning by articulating the relationships between concepts, and by relating new concepts to familiar ones. Many students create their own concept maps to help their learning, and many courses provide concept maps to students, which have been found to aid learning, even in the specific engineering disciplines. What is less certain is whether the act of engineering students trying to link concepts on their own improves learning.

PURPOSE
The goal of this study is to determine whether requiring students to identify links between concepts (through an assignment) helps students learn those concepts better (as assessed through examination).

DESIGN/METHOD
Students were each assigned pseudo-randomly (based on their numeric student identifier) three concepts from a set of 15 concepts that provide foundation material for a fairly descriptive course about the design of communication network equipment (UNSW TELE9751). They were asked to identify links between their allocated concepts and other concepts/knowledge that was presented elsewhere in the course, as identified by the lecture slide on which it was presented, and to explain the link in writing. Separately, students were assessed in mid-session and final exams through questions that covered both the assigned concepts and other subject matter, with differences in the performance of students who were (not) assigned particular concepts to link on questions that related to either those concepts or others that are linked to them indicates whether the linking activity helped student learning.

RESULTS
We found that in mid-session exam questions that directly addressed concepts covered in the assignment, the students who had been allocated those concepts in the assignment scored higher on those questions than the class overall (64% versus 40%). However, while the final exam referred to concepts covered in the assignment, such references were secondary to the subject of the questions, and so students who had been assigned concepts fared no better than the overall class in relevant questions in the final exam (52% versus 54%). Due to limited sample size and significant variance in exam marks (in turn due to few marks per question and often all-or-nothing marking) we could not claim that the difference in mid-session exam results was statistically significant.

CONCLUSIONS
Our study adds to a growing body of literature that gives evidence that learning improves when deliberate attention is paid to the links between concepts. Unlike existing studies, our study used an open-ended assignment to encourage students to consider the links between concepts and we found that this also enhances results of direct assessment of concepts.

KEYWORDS
Concept mapping, relationships

Introduction

In many subjects the concepts that underlie the subject are interrelated, e.g. one concept may need to be understood in order to understand multiple other concepts that depend on it. Such relationships can be considered in terms of a network, in which concepts form the nodes of the network and are linked together to show how they depend on one another. Learners often form such networks in their mind, and develop richer networks of connections between concepts as they develop their understanding of the subject and how concepts relate to one another. Such networks can also be depicted pictorially as “concept maps” (Novak & Gowin, 1984) or “mind maps”, which have proven useful to help visual learners appreciate how concepts are related, and to help students navigate through the volume of ideas that may exist within a subject. Figure 1 provides an example of a basic concept map for the telecommunications engineering subject of switching systems design. Such maps can aid meaningful learning by articulating the relationships between concepts, and by relating new concepts to familiar ones (Horton et al, 1993). Some lecturers provide such concept maps to help students learn, while some students create their own maps to help their learning. One study (Martinez et al, 2013) that tested the benefit of teachers using concept maps for engineering education found that their use improved assessment by 19%.

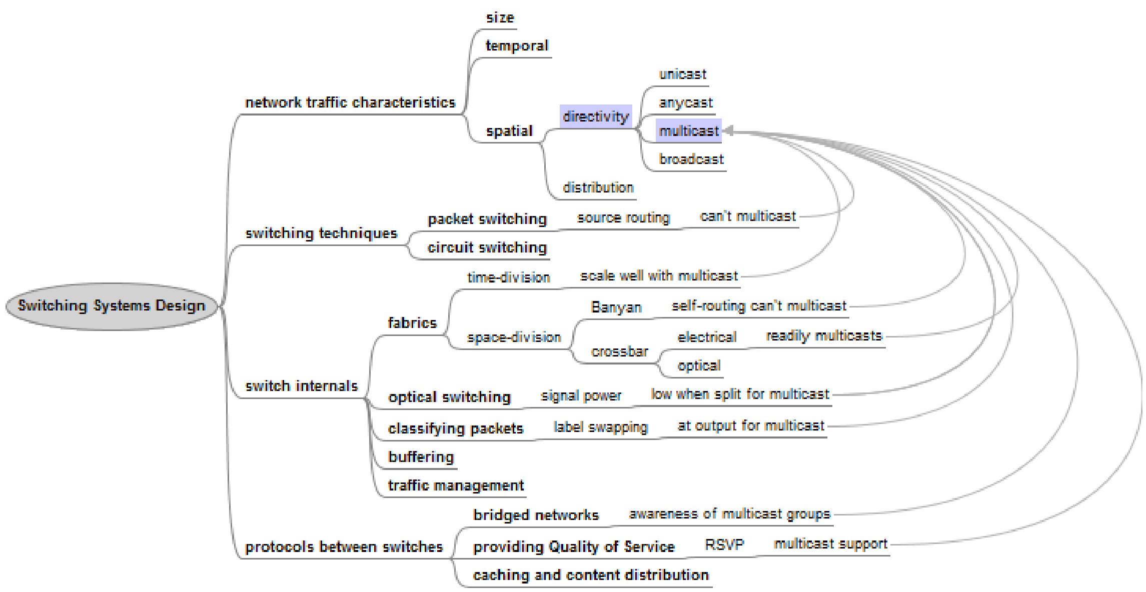

Figure 1: A sample concept map showing the structure of a course (on left in boldface) with additional sublevels for subtopics about concepts related to that of “multicast”.

In this study, we investigate whether an assignment, that deliberately forces students to reflect on how concepts in a course may be related, affects how well those students understand those concepts. Referring again to Figure 1, one such concept is that of multicasting information in a network which is one type of spatial directivity of network traffic, and in the assignment a student who was allocated that concept would be forced to consider how other concepts in the course related to multicasting, and may identify some of the relationships shown by arcs in the figure.

The contribution of this paper is in describing a novel activity that encourages students to reflect on the relationship between concepts in a course, and in reporting on the effectiveness of that activity. While the limited class size and statistical variation in assessment of understanding (in turn due to the limited number of marks per question) mean that the results are not significant in a statistical sense, they are promising in that students who had been allocated concepts to relate in the assignment performed better (64% versus 40%) on questions in the mid-session exam that direct addressed those concepts.

Recent representative investigations of using concept mapping in engineering education include the following. Martinez et al (Martinez et al, 2013) used one group of students to collaboratively develop concept maps for a course which were later used in teaching another group of students, and found that these teacher-supplied concept maps improved assessment by 19%. Another example of concept maps being supplied to students is that of Masouros and Alpay (Masouros and Alpay, 2010) who describe a web site that provided a gateway for engineering students to access electronic resources about mathematics, which included concept maps that were provided to students. Phythian and Das Gupta (Phythian and Das Gupta, 2008) also consider electronic supply of concept maps to students, and gave the results of student surveys about their perception of the value of concept maps. Turns et al (Turns et al, 2000) consider student generated concept maps (as we do in this paper) but considered their use for summative assessment of student understanding, rather than as an exercise to potentially develop student understanding. Lee et al (Lee et al 2012) also used concept maps for summative assessment, but constructed them using data from student test results and used them as a way to visualise the level of a student's understanding of the subject compared to that of an expert.

Design/Method

Our study is based on the 2013 instance of the course TELE9751 Switching Systems Design at the University of New South Wales (UNSW) which focuses on the design of telecommunication network equipment. This course covers a reasonably large set of design concepts, which leads to assessment of learning in exams being fairly evenly split between descriptive questions that cover the What, Why, How etc of the concepts (54% of marks for the final exam) and problems that apply those concepts in specific contexts (46% of marks for the final exam). We chose to focus on a set of concepts from the second week of class for the course which define the requirements for the technology that is studied in the remainder of the course and also define basic modes of operation of that technology. Those concepts were chosen because their foundational nature leads to them being referred to continually throughout the rest of the course, offering a wide range of links to other concepts that students would have the opportunity to identify. These concepts were the subject of an assignment and were assessed (with other concepts) in exams, with both assessment activities described further below.

The course presents the concepts through a lecture series that is based on a set of Powerpoint slides. As a rough approximation for this study, we equate the coverage of a concept to the Powerpoint slide on which it is first introduced. This approximation is crude, in that many slides combine multiple concepts, and major concepts are often developed over multiple slides, both to reinforce and detail a concept and to present it in the context of other concepts. However crude, this approximation does provide a useful way to identify particular "concepts" (subsets of the subject area) which then provides a basis for identifying links between concepts for the assignment, and for relating assessment questions to course material.

Assignment

Since engineering students may choose to optimise their study process to align effort with marks from assessment, we introduced an assignment, worth 10% of course assessment, that explicitly required students to find links between a set of concepts that they were pseudo-randomly allocated and concepts that were covered elsewhere in the course. Students were allocated certain Powerpoint slides ("concepts") and were asked to find other slides in the lecture series that were related. Full instructions for the assignment are available at http://subjects.ee.unsw.edu.au/tele9751/assignment_instructions.pdf . Students would then use an online form to submit a link for the assignment, on which they would identify the concept that they had been allocated, the concept that they believed was related, and an explanation (in 30 words or less) of why they thought the concepts were related. Often the relation was a reference to the allocated concept, but sometimes more abstract relationships were identified, such as analogies or complements/contrasts.

Each student was allocated three concepts from the second week of class, to aid fairness and discourage group work. In terms of fairness, the concepts vary in terms of the number of times they are linked to concepts covered elsewhere in the course (e.g. for the first half of the course, of the 15 concepts, 4 had strong links to two other slides, 3 to 3 slides, 4 to 5 slides, one to 7 slides, two to 9 slides, and one to 12 slides), and the strength or obviousness of such links. So by assigning each student three concepts to find links to, it was hoped that the total result for each student would better reflect the contribution of the student rather than the innate variability of the concepts to which they were assigned. In terms of group work, assigning each student a different set of concepts to link was hoped to hinder collaboration between students so that the mark for the assignment would reflect individual student contributions. The allocation was implemented pseudo-randomly based on the 2nd, 3rd and 4th least significant digits of student identifiers, to provide control for the study. (The least significant digit was used for another assessment task, and the more significant digits tend to be highly correlated between students, e.g. reflecting the year of enrolment, so would have enabled group work.) Each of those digits was used to select one of five concepts (e.g. a value of 0 or 1 for a digit would select concept 1, values 2 or 3 concept 2, etc) in each three groups of concepts for each student.

While the assignment did force students to try to find links to particular concepts, in doing so it also drew student attention to those concepts, so it is possible that any improvement in assessment results for those concepts was due merely to the increased attention that was paid to those concepts, rather than the activity of linking those concepts to others. Unfortunately, we found no way to decouple these possible causes.

The assignment was run in two stages, with the first stage covering links to course material covered in the first half of the course, and the second stage covering the second half of the course. Submissions were due immediately before the exam for each half of the course (mid-session or final), with this deadline chosen both to allow students to submit links that they found when revising for the exam and also to allow the exam to measure any effect of the linking assignment on understanding of concepts.

The 32 students in the class made 402 submissions for the first half of the course, and 475 submissions for the second half of the course. When marking submissions for the first half of the course, it became apparent that many students were submitting "obvious" links between a concept and slides that were presented shortly after it to elaborate on the concept or provide examples. Consequently, for the second half of the course, the instructions were revised to state that students should submit links that appear in lectures other than the one in which the concept was introduced. Since submissions through the online form were stored in a spreadsheet, we found it convenient to sort the submissions first by the allocated concept that they related to and then by the concept that was claimed to be related, so the marker could concentrate on one concept at a time. Each link was given a mark out of five, with partial marks (e.g. 2/5) awarded to students who merely linked related concepts, and additional marks were awarded to students according to the strength of their explanation of the link. For each allocated concept, the links to that concept that received the three highest marks were used to determine the student's mark for that concept, and the student's overall mark was the average of their marks for each allocated concept.

Examinations

The course included two examinations, a mid-session exam that covered the first half of the course and a final exam that only directly covered the second half of the course. Since the concepts that were allocated for the assignment were covered in the second week of the course, they were only directly assessed by the mid-session exam, but because this lecture supports the remainder of the course, the concepts covered in this lecture also reappeared as part of other concepts.

Of the 15 allocated concepts, four were explicitly tested in the mid-session exam (henceforth identified as concepts M1...M4), and five others were tested (less directly) in the final exam (henceforth identified as concepts F1...F5). Because the allocated concepts focus on requirements rather than techniques for solving telecommunication tasks, the examination questions that related to them were descriptive rather than problem solving.

Results

Table 1 lists the concept identifiers and gives the question(s) that assessed the concept, the number of students who were allocated that concept for the link discovery assignment, the number of marks for the question, and the average mark (as a percentage) for the question for students who were allocated that concept and for the set of all students in the class. A casual comparison of the marks suggests that students who had been allocated a concept for the assignment received, on average, higher marks in mid-session exam questions about that concept compared to the class overall (64% versus 40%), but fared no better than the overall class in questions in the final exam (52% versus 54%). In the analysis below, we consider why the improvement was limited to the mid-session exam and discuss the factors that hinder drawing statistically significant conclusions.

Table 1: The marks for questions about concepts covered in the linking assignment for students who were allocated those concepts compared to all students in the class.

Concept identifier(s)	Question about the concept(s)	Number of students allocated the concept(s)	Number of marks available for this question	Percentage of marks available received by students who were allocated this concept in the linking exercise	Percentage of marks available received by all students in the class
M1	What are two advantages of M1 over X?	6	4	62%	57%
M2	How can X [do] M2?	4	3	58%	32%
M3	What distinguishes M3 from X?	5	2	50%	35%
M4	Do[es] X correspond to M4.A or M4.B? Explain	6	3	83%	36%
F1	How do X and Y compare in terms of F1 and Z?	9	4	89%	92%
F2	How do A, B and C compare in terms of F2...?	4	5	25%	34%
F3	Which of A, B or C is best...for providing F3 to D?	9	2	56%	53%
F3, F4	Which of A, B or C is best...for enabling D to F3 without F4	9, 6	2	42%, 50%	50%
F5	Describe two ways by which F5 affects X	6	3	61%	41%
F5	Describe the mechanism that is commonly used to control F5 of X. ...	6	3	44%	55%

The questions, as stated in censored form in the table, are clearly descriptive, and they vary somewhat in the extent to which they assess understanding of an allocated concept. The mid-session exam questions are more direct in assessing particular concepts, while the final exam questions combine multiple concepts, with allocated concepts often being secondary subjects of the question, and one question relating to two allocated concepts (F3 and F4) amidst four other concepts (A,B,C,D). We suspect that the less direct assessment of allocated concepts in the final exam is the reason why students who were allocated those concepts did not fare better on those questions than the rest of the class.

With 32 students in the class, and each allocated three of the 15 concepts, we might expect an average of 6.4 students (32 students in the class, multiplied by three concepts per student, divided by the 15 concepts used by the class) to be allocated each concept, and that is reflected in the number of students who were allocated each concept that was covered in the exams. One final exam question asked about both concepts F3 and F4, with the one student who had been allocated both concepts scoring 50% for that question; similar to the marks for students who had been allocated one or none of those concepts. The small sample size is one factor that hinders making statistically significant conclusions about the marks.

Each question was worth a few marks, with most (7 of 10) worth 2 or 3 marks, and the remainder worth 4 or 5 marks. The number of marks allocated to each question was determined by the number of questions in the exam paper (which in turn was determined by the time available for the exam, the scope of each question compared to the scope of the course, and the depth of each question) and a School requirement that the exam total 100 marks, which led to a small number (two to five) of marks per question. The marks for questions varied to reflect the depth and breadth of the particular question, e.g. the question about F3 merely asks students to name a technology and so is worth only two marks, whereas the questions about F1 and F2 ask students for more detailed descriptions that encompass multiple technologies and so were worth more marks. The limited number of marks, and the fact that many students received no or full marks for questions (only about one quarter of students received intermediate marks) led to standard deviations of around 40% for each question. This wide variability and the limited number of samples make it impossible to show that the improvement in marks for questions about concepts that students had been allocated were statistically significant compared to the null hypothesis.

Conclusions

This study has proposed a new way to encourage students to think about the relationships between concepts, namely through an assignment in which they submit perceived links and justify them. While the limitations of our study, including small sample size and marks that intrinsically varied substantially in a statistical sense, prevent us from claiming that the assignment made a statistically significant improvement to assessment outcomes, our study does provide some evidence that engineering students do learn concepts better (as measured through direct assessment) when they are required to find links between those concepts and others in a course.

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