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Exploring Concept Maps as Study Tools in a First Year Engineering Biology Course: A Case Study*

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Concept maps are metacognitive study tools created and used by learners as reference maps describing relationships between concepts and specific domains. The purpose of this study was to investigate any correlation between the quality of concept maps and the mark distributions in a first-year engineering biology course. Major concepts of the course included prokaryotic and eukaryotic cell structure and composition, metabolic pathways, cell transport, genetic engineering and growth kinetics. Students were asked to develop concept maps and were allowed to consult their maps in a portion of the final exam. Maps were assigned a qualitative grouping of 1 (incomplete, preliminary map) or 2 (complete map) and were associated with final exam grades to compare the effectiveness of the concept maps. Students who provided complete concept maps had significantly higher 'open book' portion grades ($p < 0.0001$) and overall final exam grades ($p < 0.0001$) than students who handed in preliminary maps. The quality of the concept map was positively correlated to student performance in questions requiring conceptual skills as well as in the overall final exam grade.

Keywords: assessment; concept mapping; engineering biology; student performance

1. Introduction

Concept maps, or cognitive maps, are schematic representations of relationships between concepts. Developed as a learning tool in 1972 by Joseph D. Novak, the construction of concept maps are thought to enhance meaningful learning by improving conceptual understanding and 'learning how to learn' [1] (Fig. 1). Concept maps have been used as teaching and learning tools in mathematics, science education, humanities and social sciences, and to some extent engineering education [2–3].

In teaching, the intended learning outcomes of concept maps include: clarification of concepts; definition of conceptual schemes; correction of misconceptions; overcoming of cognitive obstacles; planning and testing educational activities and promoting self-awareness [4]. Much attention has been given to the assessment of the functionality of concept mapping as a learning and cognitive tool [5]. For example, Kitchin [6] reviewed the justification of studying cognitive maps by demonstrating their role in behavior, decision making, learning and acquisition of theory. Further applied research has shown the potential use of diagnostic mapping in formative assessment by examining students' mapping and researchers' mapping as an externalization and reconstruction of knowledge, respectively [4]. Turns *et al.* [7] also used concept mapping in course-level and program-level assessment in education engineering by gauging individual student learning and overall group knowledge and level of expertise.

The construction of effective concept maps has been thoroughly reviewed [8]. Briefly, the key features of these maps include: a familiar domain or focus question; relationships with linking words (propositions); hierarchy; cross-links and specific examples. Constructing a concept map involves: choosing a focus question that defines the context of the map, identifying key concepts that apply to

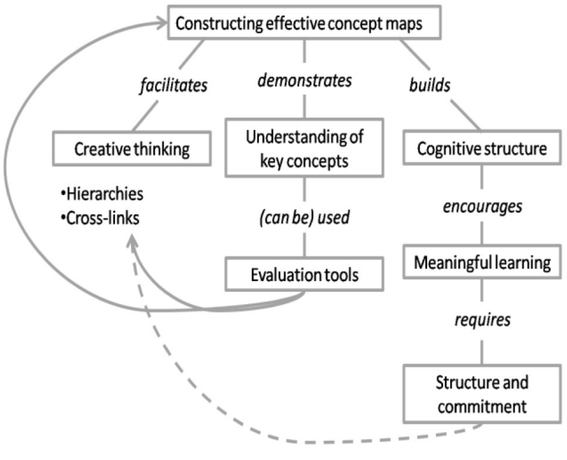

Fig. 1. Example of a concept map showing the effectiveness of this learning tool.

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this domain for the construction of a preliminary map that can then be linked in various combinations to the domain using linking words or to each other via cross-links [8]. Students may be given free rein on their concept map, although reliability may be a problem with omitted concepts and graphical barriers [4]. The use of concept maps has been researched in various fields of engineering [2], including mechanical engineering, environmental engineering, and more recently in chemical engineering [9–10]. For example, Muryanto [9] explored the use of concept maps as a learning tool for chemical engineering laboratories. The study was implemented in three stages: (1) introduction to concept maps, (2) construction of concept maps during a pre-lab session with an oral test and (3) submission of final reports along with concept maps. Three key findings were found. The first stage produced rudimentary concept maps, which became more complex, potentially demonstrating meaningful learning. Secondly, each student wanted acknowledgement for contribution, demonstrating self-motivation and thirdly, students seemed to get a feeling of continuity [9].

There is an absence of case studies exploring a correlation between the use of concept mapping in education, including engineering education, and performance based on grades. This research seeks to correct current limitations in linking grades to quantitative analysis of maps by exploring the use of cognitive mapping in a first year engineering biology course in chemical engineering. The course is designed to introduce students to the basics of biology, biochemistry, microbiology, genetic engineering and biotechnology and serves as the foundation course for subsequent biochemical engineering courses in the chemical engineering curriculum. Major concepts detailed in the course outline included prokaryotic and eukaryotic cell structure and biochemical composition, metabolic pathways, cell transport, energetics and growth kinetics. Students were given instructions for constructing effective concept maps and were encouraged to create maps that they would be able to access for a portion of their final exam. It was hypothesized that a thoroughness and accuracy of concept maps might show a positive correlation with higher final exam grades. Multiple factors were considered including question type, access to concept map and the overall final exam grade. Based on univariate and multivariate analyses, it was shown that students who constructed concept maps showing high conceptual understanding with a clear framework of key concepts and the inclusion of cross-links had significantly higher overall final exam grades than students who handed in incomplete maps and maps lacking hierarchical structure.

2. Methodology

The potential participants in this study were approximately 75 undergraduate students enrolled in a first year engineering biology course in chemical engineering. Students were informed that this study had been reviewed and received ethics approval through the University Office of Research Ethics, but that the final decision about participation was optional. Students were guided through the proper design of concept maps during their tutorial sessions via an oral PowerPoint presentation and an introduction to IHMC CmapTools software (Institute for Human and Machine Cognition, Pensacola, FL) based on the works of Novak and Cañas [8]. Students were then asked to design practice concept maps during subsequent tutorial sessions and offered assistance if they sought it.

Students were allowed to refer to their final two-sided 8.5″ × 11″ concept map during a portion of their final exam. The concept maps were collected along with the final exams, analyzed qualitatively for thoroughness and accuracy, and divided into two groups (Group 1: preliminary maps with little to no logical flow and hierarchical knowledge structure, and Group 2: complete maps that included cross-links between concepts indicating a higher conceptual understanding).

The grades obtained in the final exam were classified based on question number (see Table 1 for question description and assessment of learning and degree of difficulty), 'closed book' portion, 'open book' portion (the section allowing use of concept map representing question 1 to 5), and overall grade. Questions included in the 'closed book' portion of the exam consisted of definitions, fill-in-the-blanks and short answers. The questions in the 'open book' portion of the final exam were prepared as effective assessment tools of student learning according to problem-based learning theory, with the first objective of preparing objective questions that tested student comprehension, and with the second objective of creating problems requiring demonstration of depth of understanding [11]. Assessment of learning difficulty was determined by ranking questions based on student averages (Level 1 as least difficult, to Level 5 as most difficult). The degree of difficulty of the questions were subjectively ranked according to Bloom's Revised Taxonomy [12–13], with the 'closed book' portion of the final exam assigned a degree of 1 (Remembering). Grades from other aspects of the course were not considered.

A quantitative analysis comparing final exam grades and concept map grouping was performed using univariate and multivariate statistics. Analyses included two-tailed unequal variance t-tests

Table 1

Q1	This question is based on calculating the biomass yield coefficient ($Y_{X/S}$) and the product (lactic acid) yield coefficient ($Y_{P/S}$) from glucose metabolism stoichiometric equations, *requiring* understanding of ATP production and consumption. LD = 5; DD = 3 (Applying)
Q2	This question is based on a flow diagram illustrating the sub-cloning of an *E. coli* gene into a plasmid, *requiring* comprehension of restriction enzymes and cloning. LD = 2; DD = 2 (Understanding)
Q3	This question refers to a figure obtained for the enzyme alanine aminotransferase and the effect of various treatments on enzyme stability, *requiring* knowledge of enzyme activity and understanding protein denaturation and substrate inhibition. LD = 3; DD = 5 (Evaluating)
Q4	This question is based on a figure representing three scenarios following a switch from batch fermentation to continuous operations and cell mass concentration in the reactor, *requiring* understanding of bioreactor conditions and maximum specific growth rate. LD = 4; DD = 4 (Analyzing)
Q5	This question refers to bioaccumulation of metals by microorganisms in a bioremediation setting and asks that the student design and describe an alternative experiment for enhancing this bioaccumulation, *requiring* knowledge of transport across biological membranes and understanding the transport mechanisms involved. LD = 1; DD = 6 (Creating)

Learning difficulty (LD) based on Group 1 and Group 2 student averages with ranking from Level 1 (least difficult) to Level 5 (most difficult). Degree of difficulty (DD) based on Bloom's Revised Taxonomy [12], with the 'closed book' portion assigned a degree of difficulty of 1 (Remembering).

[Microsoft Excel], generation of a Pearson's correlation coefficient matrix, principal component analysis (PCA), unweighted pair group method with arithmetic mean (UPGMA) clustering with Euclidean distances, and K-means clustering [Statistica 8.0 software]. The normality of the data was evaluated and verified through formal statistical tests as described by Weber *et al.* [14].

3. Results

Of the potential 75 participants, 56 students (74.7%) agreed to participate in the study. This group of participants was found to be representative of the class based on a comparison of their final grades. p-values obtained showed that only results from Question 5 showed significant differences at the 95% confidence level between the means of students who agreed and students who did not agree to participate in the study (p = 0.011706), while means from questions 1 through 4, the 'open book' and 'closed book' portions, and overall final exam grades were not significantly different (Table 2).

Concept maps of participants were analyzed qualitatively and divided into two groups. The concept maps in Group 1 were considered incomplete and preliminary with unclear key concepts and little apparent hierarchical structure. Group 2 concept maps included most of the topics covered during lectures including mathematical formulas and graphs, either as key concepts or examples, as well as the inclusion of cross-links showing strong conceptual understanding (Fig. 1). An example of a Group 2 concept map showing readily identifiable key concepts and cross-links is given in Fig. 2. The student-generated concept map shows critical evaluation and understanding of concepts by selecting the major course topics of cell growth, metabolics, cell composition (monomers) and genetic engineering (cloning). The hierarchical structure of the map and the dashed cross-links indicate commitment and creative thinking. T-tests comparing the two groups showed significant differences at the 95% confidence level between the grades of the two groups (Table 3). Specifically, Group 2 grades from the 'open book' section were significantly higher than those from Group 1 with the lowest p-value of 0.000012. Of the questions, Question 3 and 4 showed the highest differences in means, with p-values of 0.004258 and 0.000212, respectively. Group 2 students also received higher grades in the 'closed book' portion of the final exam (p = 0.013929), indicating that students who produced higher quality concept maps showed a better performance in the exam, regardless of access to the concept map. Whether these higher grades were a result of overall stronger students or students who benefited more from the construction of their concept map is unknown.

Multivariate analysis confirmed the results from the t-tests. For example, Pearson's correlation coefficient indicated a correlation between higher qual-

Table 2. p-values comparing average grades between students who volunteered for the study and those who abstained

	p-value
Q1	0.853068
Q2	0.345175
Q3	0.500152
Q4	0.858885
Q5	0.011706
Open book	0.312860
Closed book	0.269748
Overall	0.268873

Group 1 (n = 15) and Group 2 (n = 40) students.
p-values attained using a two-tailed unequal variance t-test.

Fig. 2. Example of a Group 2 concept map showing key concepts and cross-links constructed by a student participant (student permission granted).

ity concept maps and higher grades (Table 4). The PCA ordination showed that while some Group 2's segregated with Group 1's on the ordination plane, the Group 1 students appeared more closely related overall than Group 2 students (Fig. 3(b)). The corresponding loading plot (Fig. 3(a)) showed that the grades obtained in the 'open book' portion of the final exam were more influential in creating the groupings seen in Fig. 3(b) than the grades attained in the closed-book section, suggesting that the creation of complete concept maps correlates better with improved open book examination (concept integration and extension questions) grades than improved closed book examination (memorization or rote learning style questions) grades. As recommended by Legendre and Legendre [15] PCA findings were also confirmed by UPGMA and K-means clustering analysis (data not shown).

Table 3. A comparison between the grades (represented as means out of 100) of Group 1 ($n = 15$) and Group 2 ($n = 40$) students. p-values attained using a 2-tailed unequal variance t-test

	Group 1	Group 2	p-value
Q1	35.778	55.917	0.010198
Q2	54.667	72.000	0.023837
Q3	50.222	68.667	0.004258
Q4	34.000	58.250	0.000212
Q5	77.000	89.125	0.044892
Open book	49.538	68.038	0.000012
Closed book	57.429	67.143	0.013929
Overall	52.300	67.725	0.000015

The learning difficulty of the questions was determined based on Group 1 and Group 2 student averages (Tables 1 and 3). A higher learning difficulty was found to correspond to a lower p-value in four of the five questions (Fig. 4). For example,

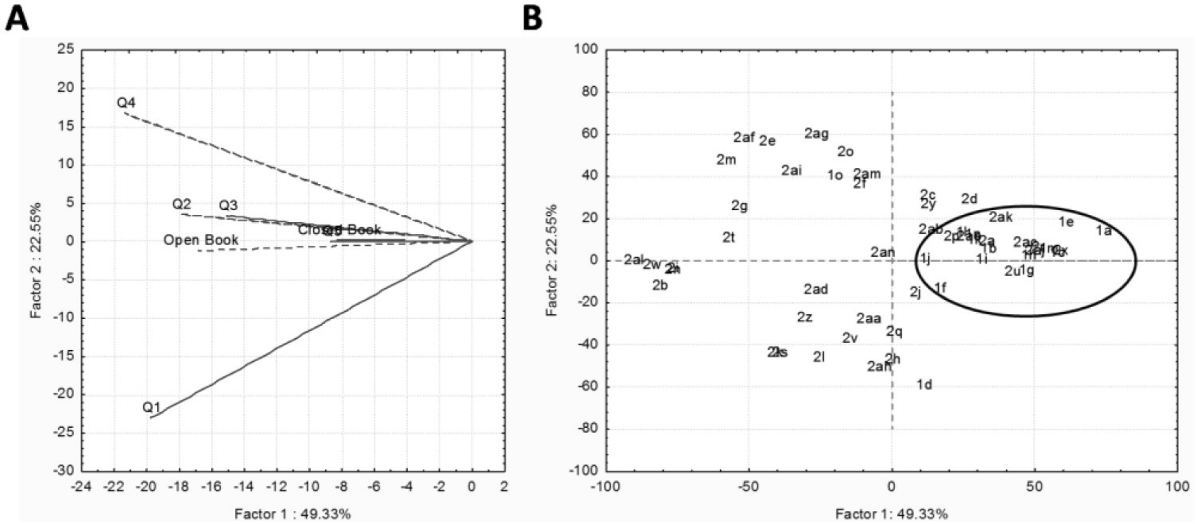

Fig. 3. Principle component analysis plots showing (a) loading of the variables, and (b) ordination of objects. Output generated using Statistica 8.0.

Table 4. Pearson's *r* correlation coefficient between average grades of Group 1 and 2. Significant values (95% confidence level) are in bold

	Q1	Q2	Q3	Q4	Q5	Open book	Closed book	Grouping (1–2)
Q1	1.000000	**0.293824**	0.264391	0.120592	0.244050	**0.669920**	**0.310953**	**0.292379**
Q2	**0.293824**	1.000000	**0.484790**	**0.446888**	0.173782	**0.745308**	**0.482335**	**0.320473**
Q3	0.264391	**0.484790**	1.000000	**0.441443**	**0.298478**	**0.730166**	**0.703844**	**0.393369**
Q4	0.120592	**0.446888**	**0.441443**	1.000000	**0.295007**	**0.646810**	**0.305465**	**0.366528**
Q5	0.244050	0.173782	**0.298478**	**0.295007**	1.000000	**0.498223**	0.211879	**0.287612**
Open book	**0.669920**	**0.745308**	**0.730166**	**0.646810**	**0.498223**	1.000000	**0.612269**	**0.491148**
Closed book	**0.310953**	**0.482335**	**0.703844**	**0.305465**	0.211879	**0.612269**	1.000000	**0.328278**
Grouping (1–2)	**0.292379**	**0.320473**	**0.393369**	**0.366528**	**0.287612**	**0.491148**	**0.328278**	1.000000

Question 5, the least challenging question with a Group 1 and Group 2 student average of 83.1, corresponded to the highest p-value of 0.044892. Question 4, with a student average of 46.1, had the lowest p-value of 0.000212, indicating a more significant difference between Group 1 and Group 2 student performance. Given that the problem-based questions were designed to test for student comprehension and concept assimilation, it is possible that concept maps were more constructive in challenging questions of higher learning difficulty.

The degree of difficulty of the final exam questions were ranked according to Bloom's Revised Taxonomy [12–13]. The percent differential between Group 1 and Group 2 student grades increased from the level 1 (Remembering) to level 4 (Analyzing) (Fig. 5). However, there was no correlation found between level 5 (Evaluating) and level 6 (Creating), perhaps because each question had sub-questions that were of varying difficulty and questions seeking creative answers were potentially graded with more leniency.

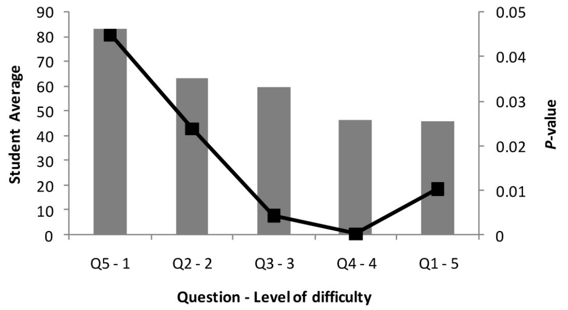

Fig. 4. A comparison between the learning difficulties of questions based on student average and corresponding p-value of Group 1 and Group 2 students.

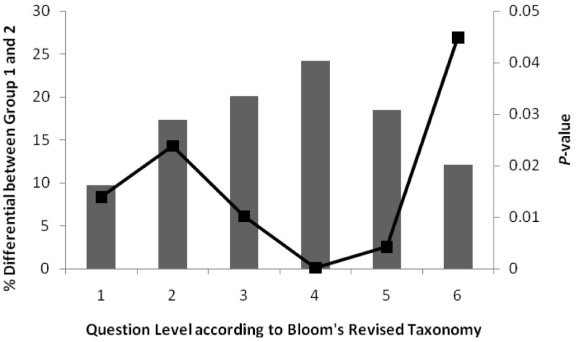

Fig. 5. A comparison of questions ranked by degree of difficulty according to Bloom's Revised Taxonomy based on student average differential between Group 1 and Group 2 students and corresponding p-value.

4. Discussion

Research has found that concept maps have limitations as research tools and become relevant mostly when combined with other methods [4]. This is especially the case when attempting to compare student knowledge quantitatively, based on concept maps using numerical descriptive variables such as structure, size, correctness and content [4]. This study has shown that concept maps can be used as important research tools in student learning and knowledge assimilation based on an assessment of overall concept map quality and content in relation to grades separating concept maps into two groups. Superior caliber concept maps were positively correlated with higher grades, especially when students had access to their concept maps for a portion of the exam. According to average grades, complete concept maps were also more constructive in questions of higher learning difficulty. However, a comparison of concept maps and final exam performance were the only factors considered for this study. Other variables such as student performance throughout the semester, in particular the midterm exam, may have been a useful indicator of improvement, both in concept map development and grades.

Concept maps have been shown to improve meaningful learning by organizing knowledge in hierarchical frameworks representing relationships [8]. This orderly sequence can then facilitate long-term memory development from 'short term' memory or working memory. In contrast, knowledge gained from rote learning does not tend to develop into long-term memory and does not enhance knowledge structure [8, 16]. The research described may confirm this finding, given the significantly higher average grades of Group 2 students in the closed book portion of the final exam. Although concept maps were not used, it is possible that the construction of the map led students to achieve higher grades due to this enhanced knowledge structure. However, questions from the closed book portion were not designed to assess student comprehension. The inclusion of questions testing depth of understanding without access to a concept map may have been useful in demonstrating higher meaningful learning.

5. Conclusions

There is an absence of quantitative analysis researching the use of concept mapping in education and performance based on grades due to the difficulty and subjectivity of analyzing student-generated concept maps. This research indicates that first-year chemical engineering students who constructed concept maps showing high conceptual understanding and creative thinking had significantly higher overall final exam grades than students who handed in incomplete and preliminary maps. It also appears that construction of concept maps may improve knowledge structure by enhancing higher meaningful learning. Given that high quality concept maps were positively correlated to performance, students would benefit from the instruction and use of cognitive mapping as study tools in education.

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