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Work in Progress: Exploring Developing Knowledge of Mathematical Modeling Skills Using Concept Maps

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Exploring Developing Knowledge of Mathematical Modeling Skills using Concept Maps

Abstract
This paper describes a work-in-progress study investigating the use of concept mapping for assessing students' conceptual knowledge over a semester in a biomedical engineering modeling course. The concept maps are used to evaluate the evolution of students' skills in developing mathematical models that describing biological systems and students' specific content knowledge as they complete problem-based learning projects. As students gain experience developing mathematical models to answer open-ended problem-based learning questions, we hypothesize that their conceptual understanding of mathematical modeling and of the biological systems studied will increase. This improved conceptual understanding is reflected by concept maps with increased complexity.

Motivation
A concept map is a visual tool used to organize and represent knowledge. Developed in 1972 based on the constructivist pedagogy of Ausubel [1], a concept map is a hierarchical diagram that shows the relationship between different concepts, ideas, or other pieces of information originating from a key concept. Concepts are represented by nodes, and the relationships between them are represented by lines or arrows that contain a linker word or phrase that describes that relationship [2]. Concepts increase in specificity as they progress further away from the key concept. Arrangement of a series of related concept-links in a hierarchical chain represents a domain of knowledge. The relationship between different domains of knowledge is indicated by cross-links, which are also connected using labeled lines, describing the nature of the relationship [3]. These connections between different segments are known as cross-links and show interrelationships between concepts. The presence of crosslinks that connect multiple upstream nodes to a downstream node reflect increased concept map complexity and the extent of knowledge integration [4].

The use of concept maps has been shown to have numerous benefits to student learning. Concept mapping has been shown to promote collaboration, as the visual format allows for efficient exchange of ideas between students [5] and helps instructors identify students' misconceptions of topics [6]. Concept maps also promote meaningful learning [7 - 9] and increase exam scores [10, 11]. Concept maps can be used as an instructional tool [12] as well as a form of assessment [13] [14]. When compared to novices, experts have significantly increased concept map quality measures [15]. Improved concept map quality over time in longitudinal studies has also been shown to reflect the gain of conceptual knowledge [16]. In this study, students gain skills in mathematical modeling through the completion of problem-based learning (PBL) questions and concept maps are used as a tool to assess students' understanding of mathematical modeling.

Class Description
Modeling Cellular and Molecular Systems (BME 260) is a sophomore- and junior-level course at Duke University. The learning outcomes are that students: 1) apply mass and energy conservation laws; 2) perform kinetic analysis of reactions; 3) work collaboratively on a team to develop and solve mathematical models; and 4) develop technical writing and oral presentation

skills. The course uses a blend of lecture, in-class and homework problems, and open-ended PBL modules.

PBL is based on a constructivist pedagogy, requiring students to work together to create solutions to complex, open-ended challenges. Since BME 260 focuses on modeling, PBL challenges were structured to engage teams to develop multi-compartment conceptual models. Teams also developed novel mass accounting and kinetic equations for important chemical constituents in their biological system, searched the peer-reviewed literature for appropriate numerical values, numerically solved the equations using Python, and presented the model and its numerical results. Sample PBL topics include Effect of Antibiotics on Microbial Cells and Modeling the Impact of Molecular/Cellular Diseases on Blood Function.

Following a 3-week instructor-led "practice" PBL (labeled PBL0), student teams work on two modeling assignments (PBL1, PBL2). PBL0 takes place over the course of six class periods, in which students model glucose regulation in the body. Students learned how to create compartmental models, generate accounting equations, and generate and interpret results. The compartment models simplify the human body into key organs/units to track the flow of chemical constituents. The accounting equations describe the mass balance of glucose, insulin, and glucagon in each compartment of their model. Students then use this information to generate results showing the quantities of chemical constituents in different compartments and critique the clarity and quality of figures. PBL1 is completed in teams of six or seven students over a 4-week period; in 2023, the project focused on tracking gas exchange in the lungs. Students are tasked with creating a multi-compartment (three to five units) mathematical model, tracking three to five chemical constituents involved in this process, and examining how a respiratory disease chosen by each student group impacts this process. Students generate mass balance equations to describe the flow of chemical constituents in the units of their compartment models, then use differential equations to generate figures to track chemical constituents in their model in both healthy and diseased states. PBL2 takes place over a 6-week period and contains the same learning outcomes as PBL1, with the differences being a new biological process to model, more complex and robust multi-compartment models, and the addition of kinetics equations.

Hypothesis & Methods

The purpose of this study is to determine if there are differences in concept map complexity as students become more familiar with mathematical modeling as they gain experience solving problems using the PBL framework. We hypothesize that as students gain more experience with PBL throughout the semester and gain deeper mastery of the material, concept maps become more complex through an increase in the number of nodes, links, and crosslinks.

Participants are 58 students enrolled in BME 260 in the Spring 2023 semester. Students make concept maps at four time points throughout the semester: the beginning of the semester, after PBL 0, after PBL1, and after PBL2. Students receive a homework credit for participation in the study. Fifty-three students gave their consent for the use of their concept maps in this study, and the study was carried out in accordance with IRB guidelines.

Students spend 15 minutes of in-class time completing each concept map and draw them using pencil and paper. The concept maps address different focus questions as shown in Table 1.

Table 1. Concept map focus questions given to students

Question	***Prompt***
1	Please draw a concept map that reflects your current conceptual understanding of what is involved in biomedical engineering mathematical modeling? You may use, but are not limited to, the following terms: Equations, Computer program, Compartment model, Chemical constituents, Mass balance, Kinetic equations, Steady vs. dynamic, Flow rate
2	Reflecting on your completed PBL0, please draw a concept map that reflects your current conceptual understanding of glucose regulation (PBL0) and related mathematical model. Do not strictly redrawing your conceptual (i.e., boxes, arrows) model.
3	Reflecting on your completed PBL1, please draw a concept map that reflects your current conceptual understanding of your selected system and related mathematical model. Do not strictly redrawing your conceptual (i.e., boxes, arrows) model.

The questions the students are asked at each timepoint are outlined in Table 2. Before making the first concept map, the first author provided students with a brief orientation to concept mapping. Students were able to use materials from the orientation to aid them in completing the concept maps, and the orientation information was made available during each concept mapping timepoint.

Table 2. Collection timepoints for each concept map focus question.

	Time 0	**After PBL0**	**After PBL1**	**After PBL2**
Question 1	X	X		X
Question 2		X		
Question 3			X	

The concept maps have direct identifiers of each student removed and replaced with an indirect identifier number to link concept maps to each student so that changes within student can be noted. Concept maps are quantitatively evaluated by counting the number of nodes and lines present. The complexity of the concept maps are used to assess students' comprehension of these topics. The density of each concept map are determined using a line:node ratio calculated by dividing the number of lines by the number of nodes [16]. Using a relational scoring system [17], the two authors generate a validity score based on the correctness of each map's links. 0 points are given for invalid links, 1 point are given for partially valid links, and 2 points are given for correct links. The final validity score is an average of the scores given by both authors. The qualitative evaluation metrics for each student are averaged together for each time point to evaluate changes in concept map complexity over the course of the semester at each timepoint.

Results & Discussion

At this time, concept maps at Time 0 and After PBL0 have been collected and preliminary analysis has been done. Data collection will be complete at the end of the Spring 2023 semester in May, and the remaining data will be processed as outlined above.

Data from Question 1 gathered at Time 0 and After PBL0 shows statistically significant changes in the number of both lines and nodes, with students having more nodes and lines after PBL0 (Figure 1). This suggests that students have gained conceptual knowledge about mathematical modeling after completing PBL0. However, there is no significant difference in the number of crosslinks or the line:node ratio, indicating that there was no change in concept map density between the two timepoints.

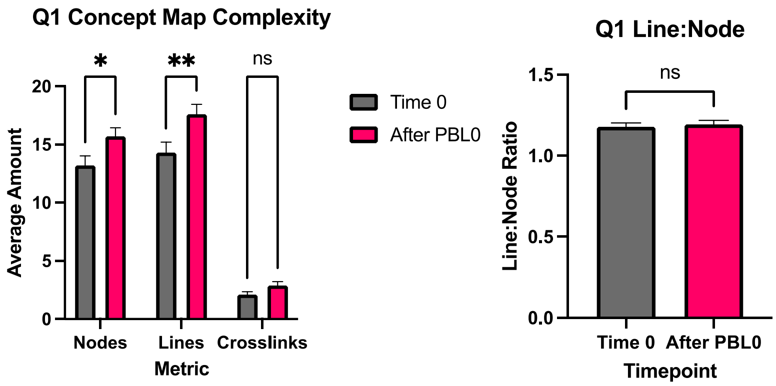

Figure 1. Comparison of Question 1 concept map metrics between two timepoints. *p<0.05, **p<0.01 by two-tailed unpaired Student's t-test with Welch's correction; error bars represent SEM; n=53 students

When comparing changes between individual students at Time 0 and After PBL0, there was an even greater statistically significant difference between the number of nodes and lines between Time 0 and after PBL0 (Figure 2). This suggests that individual students show an increase in concept map density after gaining experience with PBL problems. There is no significant difference in concept map interconnectivity at the two timepoints, demonstrated in the number of crosslinks and the line:node ratio. While most students saw increases in complexity between the two timepoints, some students showed a decrease in the number of lines and nodes. One explanation for this could be the amount of time spent on each concept map. At Time 0, students were given 15 minutes to complete one concept map. However, After PBL0, students were given 30 minutes to complete two concept maps (Questions 1, 2). Even though the amount of time to complete each map was the same, students may have not allocated the 30-minute timeslot evenly between the two maps.

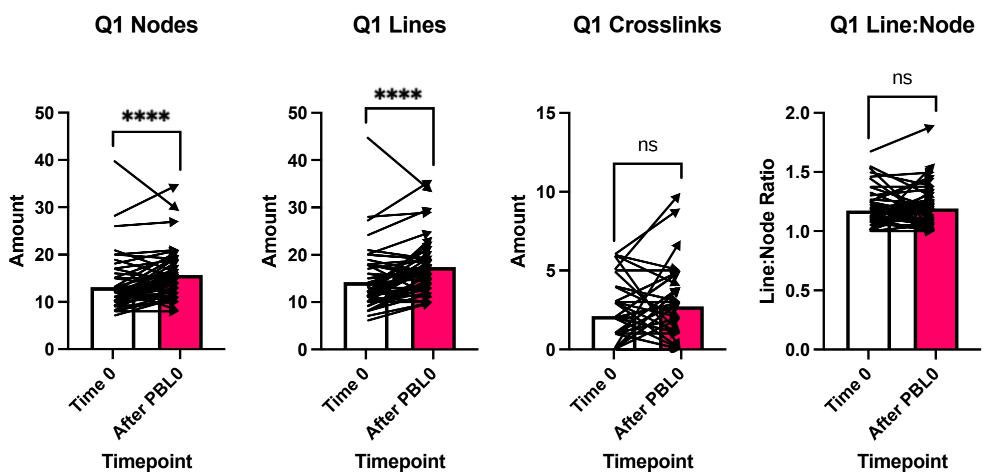

Figure 2. Pairwise comparisons of Question 1 concept map metrics between two timepoints. Arrows represent differences between individual students, and bars show the average value across all students. ****p<0.0001 by two-tailed paired t-test; n=53 students

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