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Concept Mapping for Cognition in Numerical Methods

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Concept Mapping in a Numerical Methods Course

Abstract

Concept mapping serves as a vital visual tool that supports the cognitive development process for engineering students. The finding from the research shows the potential of concept maps as a supportive educational tool; they provide a visual representation of students' thinking enhancing first-principle approach to engineering problem solving.

This research aims to evaluate the benefits of concept maps as a teaching tool in mechanical engineering education. The focus is on two aspects: technical concepts and entrepreneurial mindset concepts. For the entrepreneurial mindset, students were tasked with showing the role of engineers and computer scientists in society in creating value, and the students were expected to highlight certain keywords when developing the concept maps. For the technical aspects students were expected to create a logic flow using concept maps that serves as a criteria in determining the methods used in root finding.

This paper reviews the data from a study of concept maps as a learning tool for undergraduate mechanical engineering students in a numerical methods course. Sixty-four concept maps were reviewed and scored using qualitative and quantitative methods. We found that students typically generated more concepts for maps that focused on entrepreneurial mindset topics rather than numerical methods.

Introduction

Concept maps have been used by past researchers to assess student knowledge of topics in engineering [1,2]. As a direct form of assessment, they provide insights to faculty that may not be possible to find using other methods. In recent years they have been used as a tool to understand student development of an entrepreneurial mindset (EM). For this work, we define entrepreneurial mindset to be consistent with the Engineering Unleashed (EU) community, "*An entrepreneurial mindset (EM) influences the way you think about the world and act upon what you see. It is a collection of mental habits that empower you to question, adapt, and make positive change, leading you to: Recognize and identify opportunities; Focus on their impact; Create value in any context*" [3]. An entrepreneurial mindset has become an aspirational goal for many engineering educators as we hope that students will leave our campus ready to create value. Many studies have explored the best way to instill EM in classroom modules [4–7].

Numerical methods play a crucial role in solving real-world engineering computational problems. These methods are instrumental in modeling mechanical systems, optimizing algorithms, and addressing computational challenges such as solving complex differential equations, which govern our day to day life. Engineers encounter numerical methods first as students and continue to use these methods throughout their school and careers.

It’s common for students to find mastering numerical methods difficult. This may be due in part to the abstract nature of the subject, complexity of the steps involved, and knowledge of when to apply specific techniques. Instructors on the other hand face a hard time in the effective ways to break down complex steps and promote critical thinking when teaching numerical methods. To understand this better, we focused on the following research questions.

1. How might concept maps help undergraduate students connect knowledge in numerical methods?
2. How might concept maps help undergraduate students connect knowledge about entrepreneurial mindset?

Background

Throughout the history of education, the use of visual aids and pedagogical tools has been crucial in helping convey the complex process, making it engaging and accessible for learners. In today's world of academics visual tools are used to show thought process, designs and also convey various types of data. As engineering students grapple with abstract concepts and complex problem-solving techniques, educators have sought innovative methods to facilitate understanding. Among these methods, concept mapping has emerged as a promising approach, particularly for the assessment of EM [8–10].

Davies provides a summary of concept mapping software tools and features [11]. Kane and Trochim [12] explored concept mapping for planning and evaluation. Prior research indicates that concept maps can be used effectively as an educational tool to improve students' understanding in various disciplines, not only engineering. A summary of prior work in concept mapping is shown in Table 1.

While prior studies have explored concept maps as an engineering tool, this research focuses on how concept maps can be used to address the complexity of numerical methods. Numerical methods pose their own unique challenge for students, requiring them to choose the right approach to solve specific problems by performing a predefined step by step approach, and understanding abstract mathematical concepts. Concept maps provide a visual representation of these complex numerical concepts, making them more accessible and understandable for students. This approach promotes a deeper level of understanding as students must think critically about the relationships between different numerical topics. It also encourages active learning, engaging students in the learning process and fostering problem-solving and critical thinking skills.

Moreover, the creation of these maps facilitates the identification of knowledge gaps and misconceptions, enabling tailored teaching interventions. The emphasis on concept maps in numerical method teaching not only engages students but also holds promise for long-term knowledge retention.

Table 1. Summary of concept mapping in engineering and numerical methods. Adapted in part from Weber et al. [13].

Author	Year	Student Level	Course	Methods
Fang [14]	2012	Second year	Dynamics	Students construct maps for technical topics in the course
Moore et al. [15,16]	2012	First/ second year	Statics	Use of concept maps to organize info in statics class; starting from bottom up
Barrella et al. [1]	2016	First year	Intro to engineering	Concept maps as assessment tool for course learning objectives
Mendez and Lofton [17]	2021	Third year	Fluid Mechanics	Instructor maps and student maps compared at two institutions
Weber et al. [13]	2022	Second year	Statics	Analysis of student generated maps for statics and EM concepts.
This Study	**2024**	**Concept Mapping**	**Numerical methods and EM**	**Analysis of student generated maps for technical and EM concepts.**

Methods

Classroom Activities

Prior to engaging in the concept mapping task, students underwent initial training using the C-Map software. This training included a demonstration of a simple concept map focused on "French Fries" as an illustrative example, supplemented by clear instructions to assist students in crafting their own concept maps. The provided example was intentionally straightforward and universally comprehensible.

For this research project, students were first tasked in creating a map that would help them distinguish when to use a specific method in root solving. It was required that their concep map include the word "Root Solving" . They were given the freedom to choose their specific methods of focus; they could choose from the following words to help make their concept map make sense: Bisection, Newton Raphson, Secant, loop, False Position, systems of nonlinear equations, Jacobian, Fixed-Point iteration, matrix, initial guess, graphical method, Bairstow, Muller, greenhouse gasses, circuits, open methods, bracketing methods, algebra. The students were asked to complete the concept map after completing a unit on root solving in the numerical methods course.

Figure 1 shows an example of a concept map created by a student to distinguish the best approach for root solving. This serves as an illustration of a concept map that would score well across all categories.

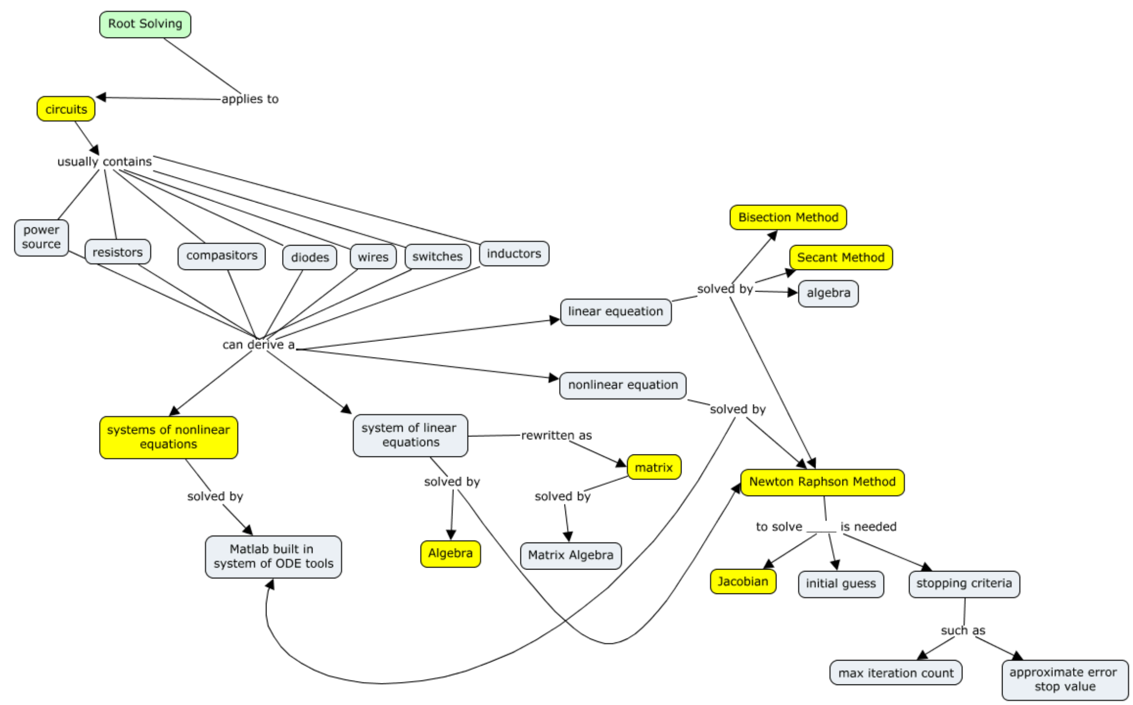

Figure 1. Example concept map for the root solving activity.

The second task occurred near the end of the course, after the students had become familiar with concept mapping software and tools. They were asked to build a concept map with the focus prompt, "*How do engineers create value?*". This prompt was selected as one of the key aspects of entrepreneurial mindset in the classroom.

Holistic Scoring method

The research team first employed a holistic method to assess the concept maps created by the students. This method involves assigning grades on a scale of 1 (lowest) to 3 (highest) , with each grade representing different levels of proficiency in the concept mapping task. The grading criteria were structured around three key categories using a rubric adapted from Besterfield-Sacre et al. [2].

Comprehensiveness: Assessed the extent to which a concept map effectively covered the key concepts of root solving methods. Maps receiving a higher score demonstrated a more comprehensive understanding of the subject matter, with a great number of concepts included.

Organization: Focused on the clarity and logical structure of a concept map. A well organized map demonstrated a clear and concise flow of ideas with effective placement of keywords and elements to convey relationships between them. A map with a high score in this category was not only visually appealing but also facilitated a more straightforward understanding of the concept to even an untrained eye.

Correctness: Focused on the accuracy of the information presented in the concept maps. A higher score in this category was awarded to maps that provided accurate, factually correct information, demonstrating a solid grasp of the root-solving concepts. Maps with inaccuracies or misconceptions were rated lower in this category. This category provided feedback on the students' grasp of the concept.

The use of holistic grading method, as a verification method for data has demonstrated its effectiveness. A study by Badia compared holistic to analytic rubrics for evaluating students' work in an information literacy instruction setting [18]. The study found that holistic rubrics offered a valuable approach in providing constructive feedback to students and informing teaching practices.

Traditional Scoring Method

The traditional scoring method for concept maps has been established by prior researchers [19]. The focus of this method is on counting elements of the maps independently. The Number of Concepts (NC) is a count of the total concepts each student included in the map. The Highest Level of Hierarchy (HH) is determined by the number of concepts connected in a line on the map. The Number of Cross-Links (NCL) is determined by the number of concepts connected from one branch to another in the map. Traditional scoring has been used widely in concept map studies, and is less ambiguous than holistic scoring since the counts are uniform.

Scoring Discussion

The holistic and traditional scoring methods were both completed independently by a pair of trained scoring experts. The scoring team then compared notes and determined the best score for each map. The scores assigned to the concept maps were compared and analyzed for variations. These variations were primarily observed in the individual assessments of comprehensiveness, organization, and correctness. In cases where discrepancies in grading occurred, both researchers engaged in a detailed discussion to explore the underlying reasons behind these discrepancies.

The discussion revolved around understanding the disparities in the concept map's score and the interpretation of the criteria. The variation in the scores prompted an in-depth exploration of the concept maps to determine whether certain aspects were potentially overlooked or misinterpreted. Such discussions not only provided insight into the individual scoring process but also enhanced overall scores. After such discussions, and careful re-evaluation of select concept maps, a general consensus was reached. The new score(s) assigned represented a shared understanding and agreement on the grading criteria. At some discussions, the variations were solved through compromise and mutual understanding.

The collaborative evaluation and consensus process were vital in maintaining the credibility and reliability of the grading process. It allowed for a well balanced perspective on the concept maps and their quality, since no two individuals are the same.

Results

The first activity for root finding methods led to interesting results in the student concept maps. Figure 1 is an example of a concept map created by a student to distinguish the best approach for root solving. Figure 2 provides an example of the type of entrepreneurial mindset map that has been generated by students.

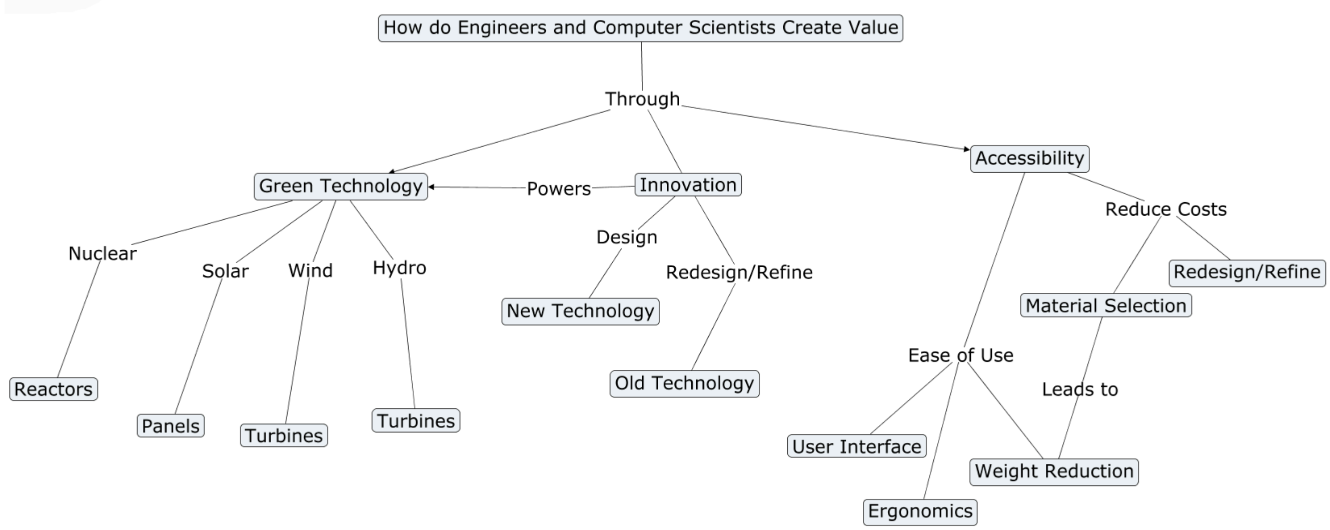

Figure 2. Example of a student generated concept map for the EM concept map activity.

Evaluation criteria, encompassing comprehensiveness, organization, and correctness, were assessed using a holistic grading method. The concept maps dedicated to root-solving methods exhibited notable clarity and directness, and attributed not only to the recent introduction of the topic prior to the research but also to the inherently more straightforward nature of root-solving concepts. The clarity was noticed in contrast to the entrepreneurial mindset concept maps, which allow for various ideas and are more open-ended.

The scores were compiled from data obtained from the Mechanical Engineering cohort at the University of Washington Tacoma and were compared to a previous study conducted at Rowan University [19] and another study conducted by Weber et al [6] at the University of Washington Tacoma on conceptual understanding of statics and entrepreneurial mindset.

Figures 3 illustrate the average distribution of scores across different categories in the rubric in all three studies. The data shows fairly consistent performance across researchers and topics. This study's scores were similar to both prior works, indicating stability in the way students approach concept maps. We noticed a common trend of having highest scores in the comprehension section and the lowest in the organization section for both EM topics and technical topics. A similar trend is observed in Weber et al's work [13].

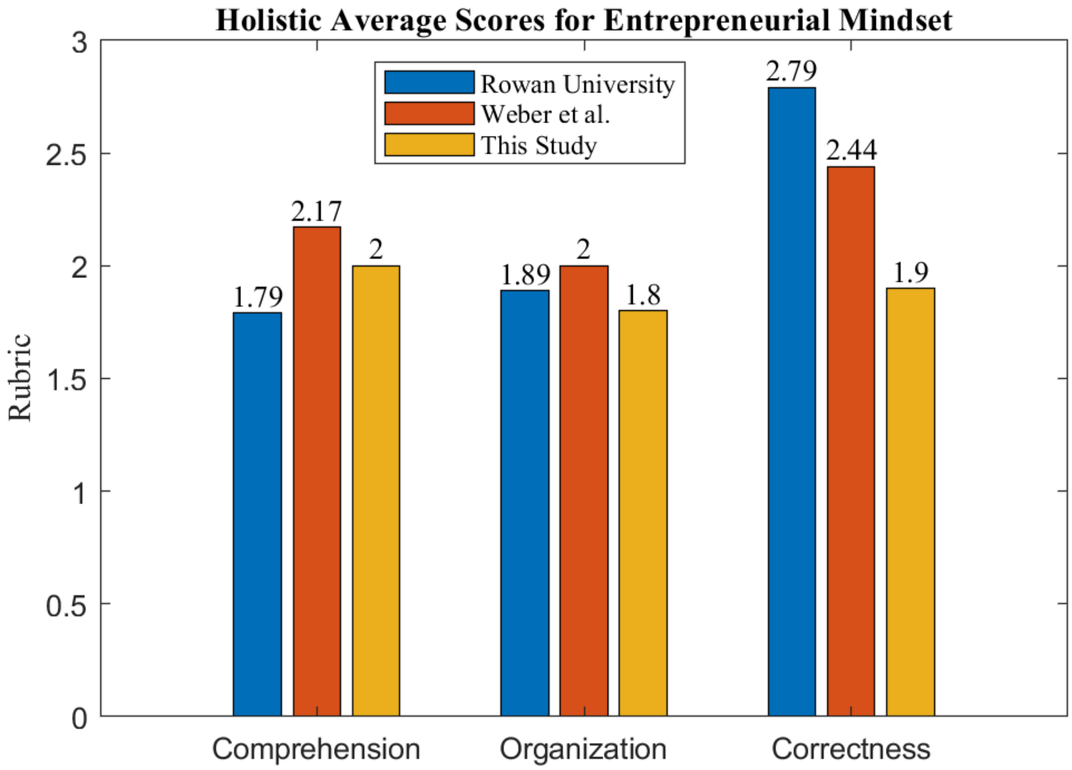

Figure 3. Average holistic score for the Entrepreneurial Mindset concept maps.

To better comprehend the variation in data and assess its validity, it is useful to examine the sample under study. Considering the substantial difference in the number of students (n) between this study and Rowan University, it becomes apparent why the data variation was more pronounced compared to Weber et al.'s work (n=9). This contrast is evident in Table 2.

The students in this study generated more concepts for the EM maps than the root solving maps, which is consistent with the findings of Weber et al. [13]. The students in this study were fairly consistent in the hierarchy and crosslinks, indicating that student population variations may be driving this data in part.

Table 2. Sample size distribution across all three researches

Category	Average for Numerical Methods in this study (n = 34)	Average for EM Maps in this study (n = 30)	Weber et al. EM Maps [13] (n=9)	Rowan University Average [19] (n = 19)
Number of Concepts (NC)	13.97	15.60	17	17.16
Highest Hierarchy (HH)	4.74	4.13	2.89	2.68
Number of Crosslinks (NCL)	1.09	1.27	1.00	2.32

Conclusions

The study sought to evaluate the effectiveness of concept maps as a teaching tool in numerical methods for undergraduate mechanical engineering students, focusing on root solving methods and entrepreneurial mindset concepts. Integration of concept maps as an instructional tool in numerical methods and engineering education as a whole presents a promising opportunity to enhance comprehension and critical thinking. The holistic grading method, despites its challenges proved to be effective in evaluating the quality of student generated concept-maps.

RQ1: How might concept maps help undergraduate students connect knowledge in numerical methods?

The comparison with studies on statics and entrepreneurial mindset highlights the unique challenges posed by numerical methods. The lower correctness scores (Figure 3) signal potential areas for improvement in teaching and learning strategies, emphasizing the importance of targeted interventions to address specific conceptual gaps. Anecdotal comments from students indicated that they found the task of generating the concept maps very helpful, but may not have the same clarity on the topic.

RQ2: How might concept maps help undergraduate students connect knowledge about entrepreneurial mindset?

From the findings it is evident that students exhibit a deeper engagement with open ended subjects, as evidenced by the higher number of correct concepts generated for the question, “How do engineers and computer scientists create value” compared to the root solving methods prompt. However, challenges such as scoring consistency and interpretation variability emphasize the need for continuous reinforcement of the evaluation process and clearer guidelines for students.

Moving forward, future research could explore the long-term impact of concept mapping on students' retention of numerical methods knowledge and their application in real-world engineering scenarios. Additionally, interventions based on the identified challenges can be implemented to improve the effectiveness of concept mapping as a pedagogical tool in STEM education.

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