Using Concept Maps in an Undergraduate Heat Transfer Course

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Dr. Najmus Saqib is an Assistant Professor of Mechanical Engineering at Marian University. He has been teaching in his field since 2017. Saqib is passionate about student learning. He received his PhD in Mechanical Engineering from Colorado School of Mines, focusing on "Optical Diagnostics of Lithium-Sulfur and Lithium-Ion Battery Electrolytes using Attenuated Total Reflection Infrared Spectroscopy". At Mines Saqib was a member of the MODES Lab, led by Dr. Jason M. Porter. His work on Li-S batteries was the first of its kind to use quantitative infrared spectroscopy for operando polysulfide measurements. He has also applied operando spectroscopy to improve the understanding of electrolyte decomposition mechanisms in Li-ion batteries. In addition to his current research interests of developing diagnostic tools for electrochemical storage of renewable energy, Saqib is also interested in the Scholarship of Teaching of Learning (SoTL) and Engineering Education in particular.

Prior to joining Marian, Saqib was one of the founding faculty members of the Mechanical Engineering program at the University of Indianapolis. He served as the program coordinator, undertaking major curriculum development, and led the program through a successful initial ABET accreditation review. He received multiple research grants, he coordinated the campus-wide Research Fellows programs, and his dedication to teaching was recognized through the UIndy Teacher of the Year nomination in 2023.

In the classroom, Saqib likes to challenge his students to tackle real-world engineering problems. He likes to use innovative pedagogical techniques and Entrepreneurial-Minded Learning (EML) to facilitate student learning. Beyond the classroom, he has a passion for mentoring students and helping them achieve their educational and professional goals.

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Abstract

Concept maps are widely used in foundational non-engineering science courses to help students express their own understanding of course material. By creating a concept map, students are able to visualize the relationships between different course topics. In recent years, the use of concept maps in fundamental engineering courses has gained growing attention. They have been reported to be very effective in providing students with an interactive learning experience by leveraging constructivist pedagogy. This work reports the effectiveness of integrating concept maps as a learning tool in an undergraduate Heat Transfer course for students majoring in Mechanical Engineering. Over the course of the semester, students were asked to create two concept maps: one for thermal conduction and one for convection. The students worked on the concept maps in small groups at regular intervals in class, and they grew as new material was covered. After student groups developed their own concept maps, instructor-created concept maps were also shared with the class immediately before exams, to serve as an exam study tool. A survey was conducted at the end of the semester to gauge student perceptions of using the concept maps. Qualitative and quantitative results from the survey are presented. The classroom approach to creating and using the concept maps was refined after the first round of student feedback data was collected. Concept maps were found to be a useful, constructive learning tool for visually connecting and organizing course topics for both students and instructors. The results are limited to a single, primarily undergraduate institution with small class sizes. Future work will seek to expand the data set by including multiple institutions. This paper provides instructions on running the classroom activity to encourage students to build their concept maps, provides examples, and presents qualitative and quantitative student feedback from multiple offerings of the course.

Introduction

A concept map (also known as a mind map or a knowledge map) is a graphical way to represent and organize relationships between course topics and ideas and draw connections between concepts [1-2]. Mapping is achieved by drawing connecting lines between concepts in a visual representation. It was introduced as an educational tool more than thirty years ago. Concept maps have been successfully used in a variety of STEM courses [3]. As engineering educators have strived to incorporate more active learning pedagogies in the classroom, concept maps have emerged as a valuable learning tool [4]. They fall under the umbrella of constructivist pedagogy whereby students create their own meaning of course concepts [5]. In Mechanical Engineering curricula, effective use of concept maps has been demonstrated in Mechanics, Thermodynamics, Fluid Mechanics, and Design courses [2,5]. These studies have reported that concept maps can help increase conceptual understanding and that new learning tools can be effectively incorporated throughout the curriculum, beyond foundational courses.

This paper describes an active approach to using concept maps in an undergraduate Heat Transfer course. Over the course of the semester, students were asked to create two concept maps: one for thermal conduction and one for convection. The students worked on the concept maps at regular intervals in class, and the maps grew as new material was covered. After students developed their own concept maps, instructor-created concept maps were also shared with the class immediately before exams, to serve as an exam study tool. Results from the study include qualitative and quantitative feedback captured using a student survey at the end of the course. The results are limited to a single, primarily undergraduate institution with small class sizes. Data was collected from two separate offerings of the course taught by the same instructor. At the institution where this study took place, only one section of Heat Transfer is offered every year.

Because there exists some disagreement in the literature on assessing student-created concept maps, they were excluded from the results of the study. Specifically, Johnstone and Otis noted that concept maps should be treated as "very personal learning tools" due to the many necessary inferences that must be made in understanding a map and the corresponding opportunities for mistakes [6]. Instructor-created concept maps are presented herein.

Methods/Classroom Approach

Students in an undergraduate Heat Transfer course were introduced to concept mapping as a learning tool in Spring 2022. The course requires both Thermodynamics and Differential Equations as prerequisites. Seven students were enrolled in the course, which is designed for the third year of the undergraduate Mechanical Engineering program at the institution.

Student mastery of course content was evaluated via homework, quizzes, in-class activities, and three exams. The exams were cumulative, but each exam focused on key concepts from recent lectures. New concepts for each exam are listed in Table 1. Permitted reference materials on the exams included only an individual equation sheet created by the student.

Concept maps were introduced to students during the first week of the 15-week course, with a short discussion to share with students the learning benefits of concept mapping. During the third week of classes, students were sorted into multiple groups and asked to create a concept map within each group based on recently covered topics. After this, students were given time during class once a week to expand their concept maps. In the week preceding the first exam, which focused on Conduction Heat Transfer, an instructor-created concept map was shared with the class. Students were reminded that there was no "correct" version of a concept map and that theirs may look different. In the week following the first exam, students were asked to begin developing a concept map for Convection Heat Transfer. In the week preceding the second exam, which focused primarily on Convection Heat Transfer, another instructor-created concept map was shared with the class. Student-created concept maps were collected at the end of the course, but they were not graded. Note that a concept map was not developed for Radiation Heat Transfer as the course schedule permitted only a brief (approximately two weeks) introduction to the topic. An instructor-generated concept map is presented in Figure 1.

The study was repeated during the Spring 2023 offering of the same course by the instructor when eighteen students were enrolled. Comparing student performance on exams from 2022 and 2023 to two other course offerings prior to incorporating concept maps, an average increase in exam scores of up to 7% was observed.

Table 1: Topics Covered on Exams

Exam	Key Topics
1	1-D Steady Conduction, 1-D Steady Conduction with Energy Generation, Fins and Extended Surfaces, 2-D Steady Conduction, 0-D Transient Conduction, 1-D Transient Conduction
2	Boundary Layers, External Flow Convection, Internal Flow Convection, Natural Convection, Heat Transfer in Tubes, Heat Exchangers
3	Blackbody Radiation, Surface Emission, View Factors, Radiation Enclosures

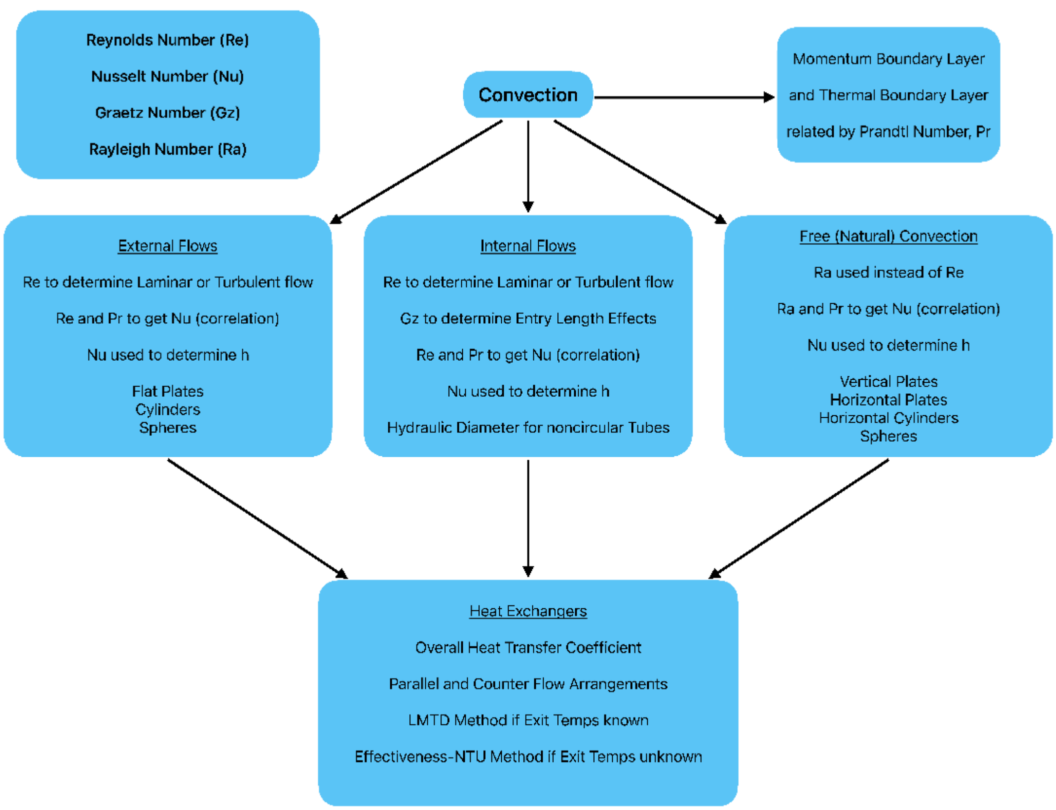

Figure 1: An example of an instructor-generated concept map.

Qualitative and Quantitative Student Feedback

In order to gather data on concept mapping in the Heat Transfer course, a survey with short-answer and Likert scale questions, to be administered at the end of the course, was developed. The anonymous student survey was distributed through Qualtrics. The questions were adapted from previous work by the author [7]. The survey results are summarized below.

Likert Scale Survey Questions

Select your level of agreement with the following statements:
(1 - Strongly Disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly Agree, DNR - Do Not Remember)

- A) *I had previously used concept maps before taking this course.*
- B) *The concept mapping activity was a group effort.*
- C) *The use of concept maps improved my learning experience in the course.*
- D) *The concept maps were a useful resource for exam study.*
- E) *I plan to use concept maps in the future.*

Table 2: Average Results of Likert Scale Survey Questions.

Semester	**Sample Size**	**Likert Scale Question Average**				
		A	**B**	**C**	**D**	**E**
Spring 2022	7	1.57	4.00	4.57	4.86	4.14
Spring 2023	18	1.67	4.11	4.28	4.11	4.06

Short Answer Survey Questions

What aspects of the concept map did you find either useful or not useful for your learning in this course?

- "The concept maps we made helped me visualize how the new topics we learned each week connected to each other."
- "They were very useful for exams, but I would like to see them used for classroom problem solving and homework."
- "I did not find it very useful for actually solving problems."

Please provide any additional comments about the use of concept maps in this course.

- "I would like to see an overall concept map for the entire course."
- "Concept maps are a great idea. We should use them in other classes."

The results of the student survey are positive and encouraging for the continued use of concept maps in future iterations of the course. Most students had not used concept maps before, but they strongly agreed that improved their course learning experience. They also agreed that the maps served as a useful study tool for exams and intend to use them again in the future. A few students noted that the concept maps did not directly apply to problem solving strategies. Perhaps a more detailed concept map complete with useful equations could help with this. One student noted that an overall map for the entire list of course topics may also be beneficial. This is an ongoing effort.

From the instructor's perspective, concept maps can be beneficial for someone undertaking a new course preparation or reviewing topics. They can also inform a reorganization of a course or alternate methods to introduce topics.

Limitations of this study include: data collected from only two offerings of the course, with only twenty-five students in total, and the lack of any demographic data. There are plans to continue this study to include larger groups of students across multiple institutions.

Conclusions

This paper describes the use of concept maps in an undergraduate Heat Transfer course. Summarizing the results from student surveys, concept maps were found to be a useful, constructive learning tool for visually connecting and organizing course topics for both students and instructors. More data could be collected to increase the sample size and account for variations in course offerings for additional evidence to be gathered on the impact of concept maps in undergraduate Heat Transfer courses. Planned cross-institutional future studies can provide additional information about this promising pedagogical tool.

References

[1] Turns, J., Atman, C. J., & Adams, R. (2000). "Concept maps for engineering education: A cognitively motivated tool supporting varied assessment functions". IEEE Transaction on Education, 43(2), 164-173.

[2] Mendez, J., & Lofton, J. (2020). "Two Approaches to Concept Maps in Undergraduate Fluid Mechanics". Proceedings 2020 ASEE Annual Conference.

[3] Lopez, E., Kim, J., Nandagopal, K., Cardin, N., Shavelson, R. J., & Penn, J. H. (2011). "Validating the use of concept-mapping as a diagnostic assessment tool in organic chemistry: implications for teaching". Chemistry Education Research and Practice, 12, 133-141.

[4] Enszer, J. A. (2018). "WIP: Exploring Mind Maps for Assessment in an Introductory Chemical Engineering Course." Proceedings 2018 ASEE Annual Conference.

[5] Noor-A-Alam, M., & Mendez, J. (2022). "Construction and Use of a Concept Map in an Undergraduate Dynamics Class". Proceedings 2022 ASEE Annual Conference.

[6] Johnstone, A. H., & Otis, K. H. (2006). "Concept mapping in problem based learning: a cautionary tale". Chemistry Education Research and Practice, 7, 84-95.

[7] Saqib, N. (2023). "A Visual Heat Transfer Exam Review Activity". Proceedings 2023 ASEE Annual Conference.