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Introducing Concept Maps in an Undergraduate Heat Transfer Course

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WIP: Introducing Concept Maps in an Undergraduate Heat Transfer Course

Abstract

This Work In Progress (WIP) outlines an approach for creating and introducing a concept map in an undergraduate, introductory heat transfer course for mechanical engineering majors. Concept maps, mind maps, or similar diagrams, provide a visual representation of relationships between course topics. These tools help students identify connections and build new neural paths, linking new knowledge to existing knowledge, which aids in both understanding and recall. While the benefits of concept maps have been widely reported, there is limited evidence demonstrating the effectiveness of concept maps in an undergraduate heat transfer course. This Work In Progress highlights the instructor-developed concept map designed to assist students in identifying and connecting concepts required for heat transfer analysis. Future work will include student-developed concept maps and data collection to evaluate the impact of concept maps on student academic performance in the course.

Background

Concept maps, mind maps, or similar diagrams, provide a visual representation of relationships between course topics. These tools help students identify connections and build new neural paths, linking new knowledge to existing knowledge, which aids in both understanding and recall. Increasing the number of concepts, and the number of connections between concepts, in a learner's mind will result in increased mastery of the subject [1]. The use of concept maps to demonstrate comprehension and understanding has been closely linked with constructivism. Constructivism views learning as an active process where learners are creating meaning by testing new concepts against prior knowledge. Concept maps are a visual tool for communicating understanding of concepts and relationships.

When generated by a subject matter expert, a concept map can act as an "advance organizer" when shared with leaners before new concepts are introduced, or as a review tool when shared with learners after exposures to new concepts [2]. When generated by a learner, concept maps can assist in organization of thought, review by summarizing, or as an assessment tool to identify knowledge gaps or errors in understanding. Maps can be revised and modified, similar to the neuroplasticity of the human brain as new neural paths are built and connected [3]. Evidence of learning could be seen by comparing a map generated by a learner when first encountering a new topic with a map generated after some time has been devoted to studying the same topic.

The benefits of concept maps have been widely reported [1-4], and various assessment techniques have been presented for studying the impact of concept maps in the classroom [5-7]. However, there is limited evidence demonstrating the effectiveness of concept maps in an undergraduate heat transfer course [8]. Much of the research related to concept maps in engineering has been conducted in mechanics courses [9-12], but there is also evidence of concept maps being integrated in thermal science courses [3,13-15].

In some studies, the researchers include caveats that concept maps are personalized tools and may be open to misinterpretation when shared with others [16]. The understanding of maps as individualized may also explain variations in both the physical structure of maps, as well as the content [10,17-19], The purpose of the concept map will also impact the format. For example, a high-level map may only contain a small number of general topics, whereas a more detailed map may expand a single topic to include many related phrases, images, equations, and diagrams. Some concept maps include decision-tree features that map a path for thought for a sequential process.

In this study, the author highlights an instructor-developed concept map designed to assist students in identifying and connecting concepts required for heat transfer analysis. The motivation for this pedagogical tool was to provide additional scaffolding for student learning, including decision points for analysis techniques used in course assignments. The instructor also wanted to directly connect the course textbook to the maps to increase student familiarity with the textbook as a reference. After several iterations, the instructor-developed map moved away from a traditional high-level concept and towards a detailed map/decision-tree. The resulting maps were shared as guides to help students identify appropriate solution methods and provide a frame of reference for heat transfer analysis.

Approach

The motivation for this study was to provide scaffolding that modeled and guided critical thinking for students analyzing a heat transfer problem. By modifying a concept map to include some decision-tree features, and references to textbook tables and equations, the instructor attempted to outline a path for students to demonstrate the highest levels of Bloom's Taxonomy. The guiding questions used to develop the concept map are listed below.

Guiding Questions:

- What is happening in the system? Describe the system. Keywords? Assumptions?
- Which equations can describe what is happening? Where can I find them?
- What inputs are needed to solve the equations? Where can I find them?

Answering these guiding questions would demonstrate all but the highest level of Bloom's Taxonomy [20]. The questions require students to remember and understand the course concepts, which allows them to identify appropriate assumptions and evaluate a system by applying corresponding equations and heat transfer models. Similar questions are regularly used by the instructor both in the classroom and in office hours when guiding students through problem solving exercises. Connecting items in the concept map to the course textbook explicitly linked lecture material from class to the textbook, guiding students to use the textbook as a reference when solving problems independently.

Concept maps were introduced as a review technique and study tool for eight mechanical engineering students throughout the Fall 2023 semester as part of a required 3-credit hour heat transfer course. The course topics are organized in such a way that exams emphasize each of the three modes of transfer: conduction, convection, and radiation. As each mode of heat transfer was covered in class, the instructor summarized new concepts by constructing a concept map or flow chart on the board with input from students. The instructor encouraged students to create and modify individual concept maps as a study tool both for in-class problem solving and for homework assignments. Students were also allowed access to personal reference sheets during exams, and the instructor encouraged making a personalized map as reference material for the exam.

The instructor regularly references the assigned textbook [21] for this course and therefor requires students to bring their textbook with them to class. When developing the concept map, the instructor connected topics to commonly referenced tables, figures, and equations to indicate the corresponding analysis techniques. Embedded textbook use required the students to better familiarize themselves with finding solutions in published reference materials rather than attempting to memorize solutions. The concept map in this study could be easily adapted to any reference by modifying the textbook notations in the figures included below.

Students were first introduced to the concept map study tool after covering steady state conduction, which included chapters 1-4 of the textbook. While asking for student input, the instructor created a limited map for steady state conduction analysis on the whiteboard that began with the Conservation of Energy and the three modes of heat transfer. The instructor asked students the guiding questions previously listed, as well as how to evaluate each term in the energy balance equation, and any keywords or hints they used to identify the presence of different energy transfer rates. This introduction led to a concept map on the whiteboard for steady state conduction similar to the image shown in Figure 1.

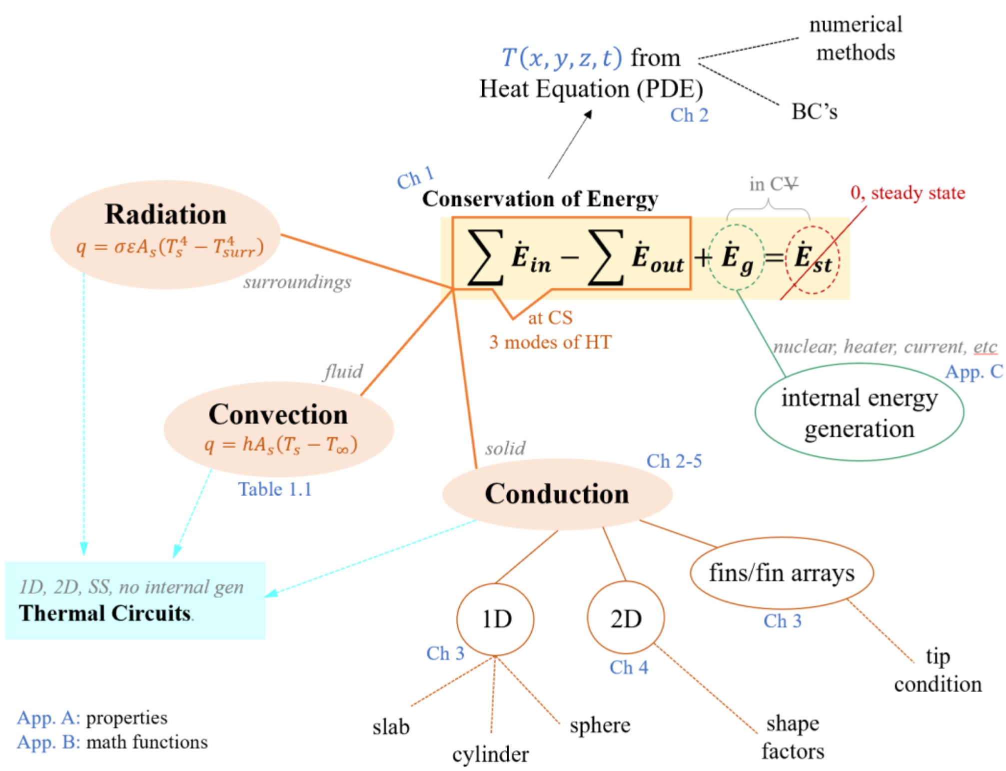

Figure 1: Introductory Conduction Map

Then the instructor asked students to identify equations that corresponded to the map items, as well as textbook references that would help them solve a homework problem with each concept. The instructor explained that identifying the system and appropriate assumptions was essential for heat transfer analysis, but it was equally important to select the correct corresponding equations and values. After some modification, students were presented with a tool similar to the map shown in Figure 2. In this course, most steady state conduction problems can be solved using thermal circuits. The instructor provided further guidance on using the tool when working independently.

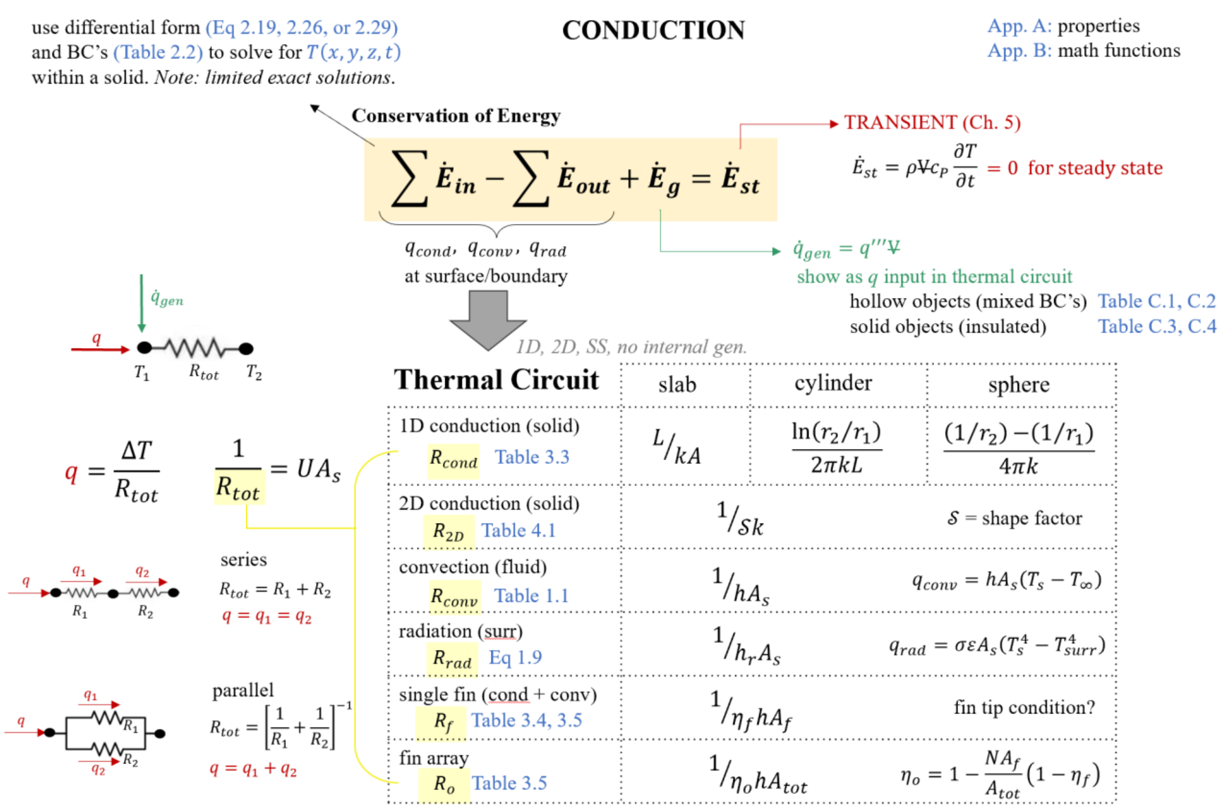

Figure 2: Steady State Conduction Map

Students were encouraged to modify and create their own versions of the concept map, including adding notes and reminders of when topics or equations would be needed to solve a problem. Students were reminded that the map organization corresponded to the instructor's approach to solving problems and could be re-organized to better align with the student's approach. Limited maps were constructed on the board at several times during the semester as new material was introduced. A limited map for transient conduction is shown in Figure 3.

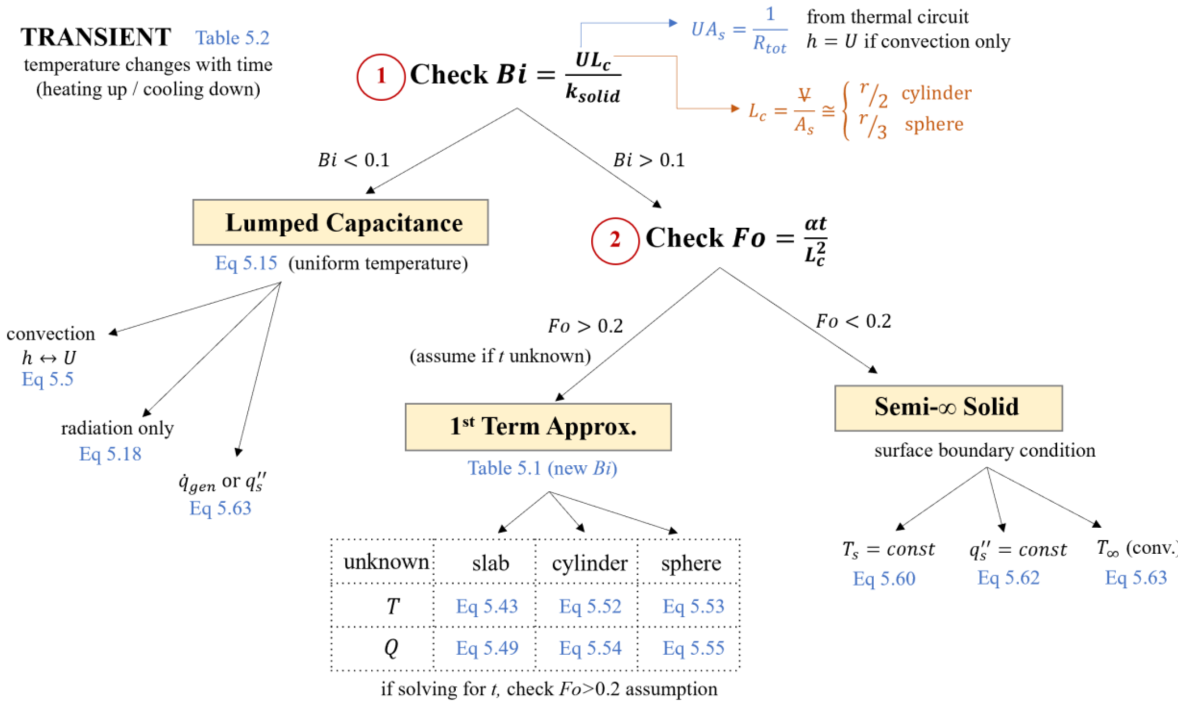

Figure 3: Transient Conduction Map

The instructor had previously incorporated a less-detailed version of Figure 3 to teach students how to select an appropriate transient analysis method (lumped capacitance, first term approximation, or semi-infinite solid approach). After experiencing students correctly identifying the method, but not the corresponding equation, the instructor added equation numbers based on identification of geometry or boundary conditions. As can be seen from the map, transient conduction analysis is well-suited to sequential ordering, or representation with if/then statements.

Limited maps were also constructed for forced external, forced internal, and free external convection before being added to an overall concept map for the course. A limited map for forced internal convection, with decision-tree features similar to a flow chart, is shown in Figure 4.

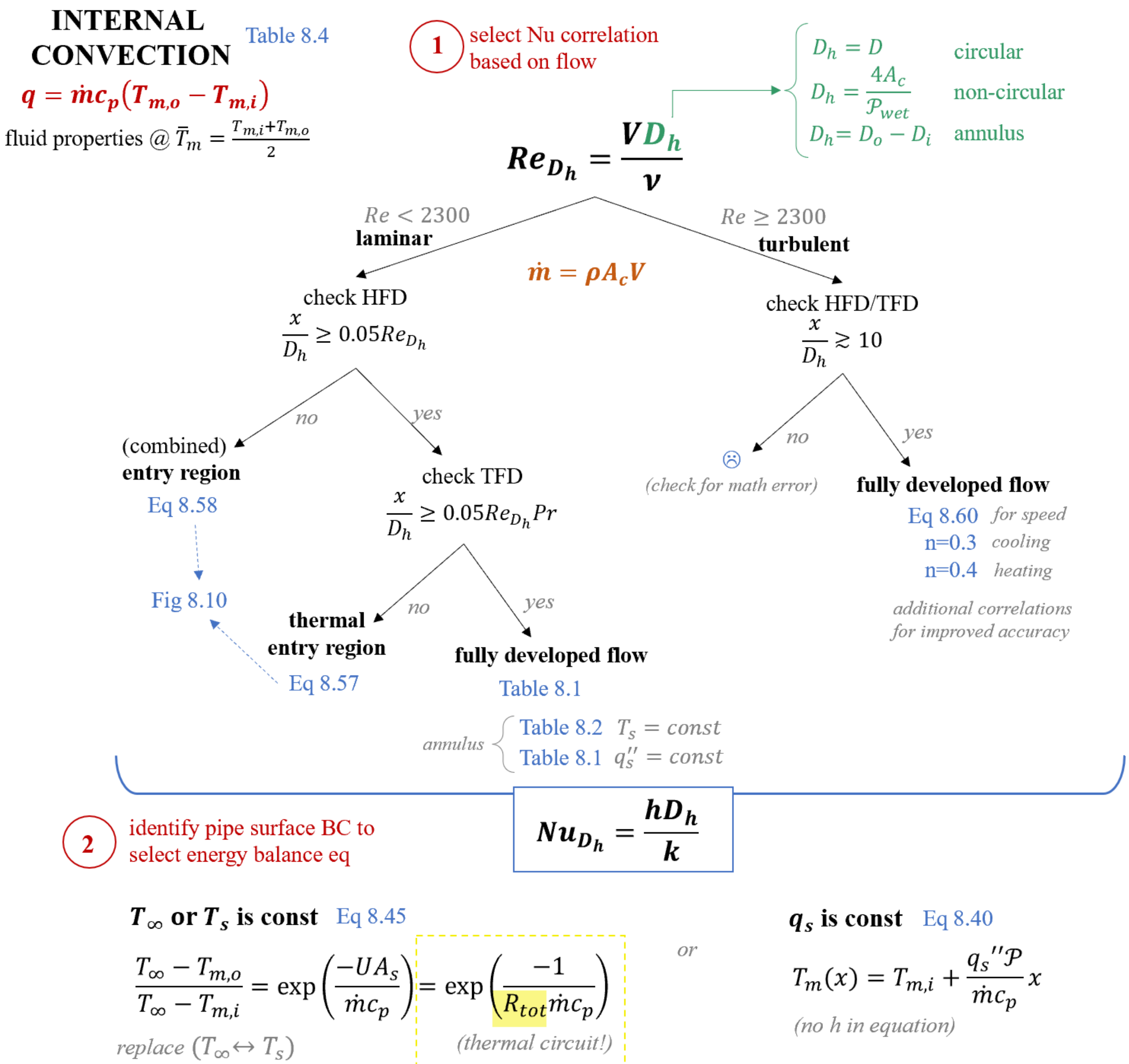

Figure 4: Internal Convection Map

As concepts of internal convection were first introduced in class, the instructor provided a handout of the internal convection map from Figure 4 to all students as a reference tool. When solving problems in class, students were asked to consult the map and provide the next step in the solution. Much like transient conduction solution methods, the process for analyzing a convection problem is well-suited to sequential ordering.

A course map, which included the key concepts from the semester, along with corresponding textbook chapters, is shown in Figure 5. This course map does not contain the detail of the previously presented maps but more closely resembles a traditional concept map.

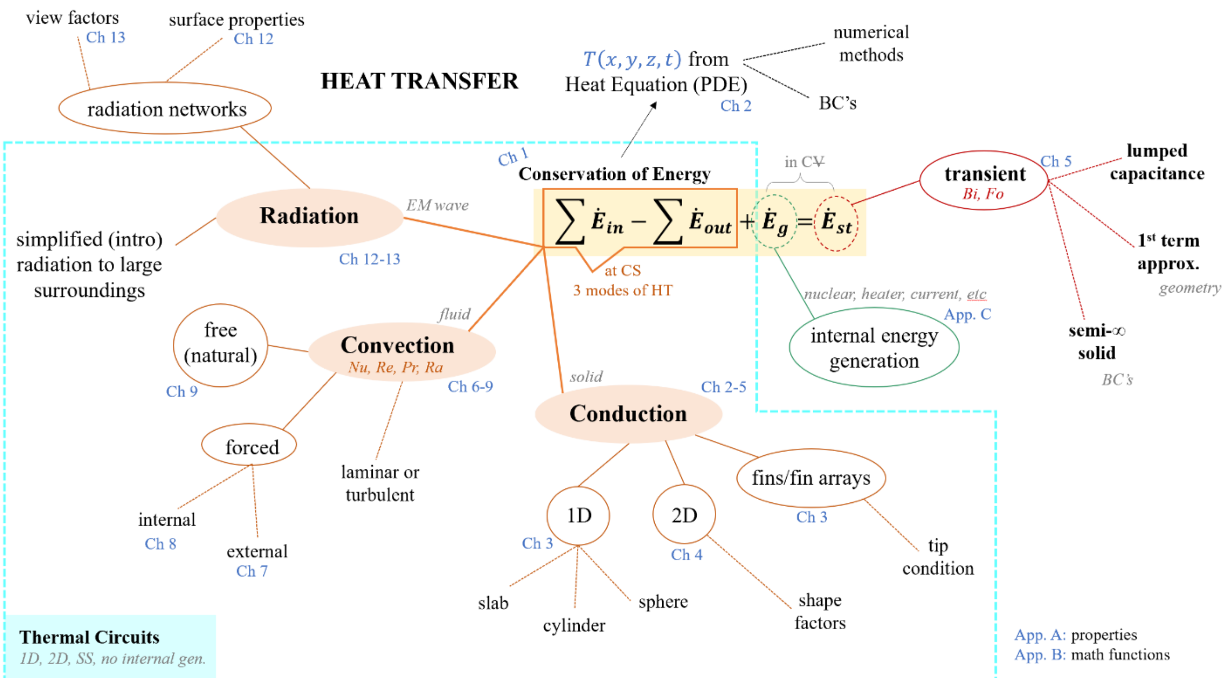

Figure 5: Heat Transfer Course Map

Figure 5 was presented to students as an overview of course topics and keywords for identifying solution techniques. Students were encouraged to combine details from the topic-based maps to expand the course map such that it included enough information to help the student select an appropriate equation or solution method for any given problem.

Results and Future Work

As a work in progress, the results in this study are limited and focused on instructor-developed concept maps. The concept maps presented have been modified from a traditional concept map to include features similar to decision-trees. The modified maps provided additional scaffolding to help students select appropriate analytical tools corresponding to concepts used to identify the and simplify the system of interest. The modified maps also directly connected concepts to the course textbook to encourage student familiarity with the reference.

While anecdotal feedback from the students was positive from the Fall 2023 semester, the class size of eight students was too small to collect meaningful data to evaluate the impact of introducing concept maps. The instructor observed students referring to the concept maps while solving problems in class and on exams. All students included some form of the concept map on the personal reference sheets permitted for exams; however, only two students appeared to have modified the map shared by the instructor. Future work will include student-developed concept maps, as well as self-reported data from student surveys on the effectiveness of concept maps in the heat transfer course.

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