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WIP: Enhancing Students Learning in Heat Transfer Course Through Scaffolded Group Activities

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Abstract

Work in Progress: Heat Transfer is an upper-division course in the Mechanical and Aerospace Engineering program, widely recognized as a mathematically intensive class which requires advanced problem-solving skills. Typical enrollment in this course ranges from 60 to 200 students and is offered in 10 weeks both in Fall and Spring. To enhance course design, students were first surveyed about the challenges they encounter while solving engineering problems. The most frequently reported difficulties included: identifying how to start a problem, selecting appropriate methods and equations, and achieving a strong conceptual understanding. To address these challenges and enhance student learning, three scaffolded group activities were developed and integrated into the course. After the first and third activities, follow-up surveys were conducted to gather feedback on students' experiences and perceptions on problem solving.

Additionally, the end-of-term course evaluation included questions about the effectiveness of the scaffolded activities on their learning experience and whether students are open to adopting flipped models, which would allocate more in-class time for guided, in-depth problem-solving practice. This work in progress will present the design of the scaffolded activities and summarize preliminary survey findings.

Introduction

The Heat Transfer course is a core upper-division course in mechanical and aerospace engineering programs at University of California, San Diego, which is typically taken in the junior and senior year. This course is a required course for mechanical engineering students and is taught by multiple instructors in both the fall and spring quarters. Student assessment is primarily based on homework assignments, in-class activities (in some sections), two midterm exams, and a final exam.

The course curriculum covers the three basic modes of heat transfer: conduction, convection, and radiation, with an emphasis on connecting physical phenomena to mathematical derivations. In particular, the conduction portion involves step-by-step derivations of the governing heat conduction equation from Fourier's law and the energy balance, followed by analytical solutions for one-dimensional, multidimensional, and unsteady conduction problems using methods such as separation of variables and eigenfunction expansions.

It is important to ensure that students not only learn these fundamental methods for solving complex problems but also understand how to connect these methods to physical assumptions and real-world situations. Prior research has shown the effectiveness of active learning and collaborative group work in enhancing student understanding [1][2]][3]. Furthermore, scaffolded design activities support student learning by reducing cognitive load and allowing students to solve problems through manageable tasks [4][5][6][7].

In this study, a series of scaffolded group activities have been designed and integrated into the course to help students develop a comprehensive, “big picture” perspective on solving complex problems. These activities encourage students to work collaboratively while applying appropriate strategies for problem-solving. This study was approved by Institutional Review Board (IRB #812320).

This WIP investigates the following research questions:

(1) What challenges do students report when solving complex heat transfer problems?

The focus of this question is to understand students' perception about what makes problem solving challenging for them. This could be the first step to trigger their metacognition and help them to develop metacognitive skills needed for effective learning.

(2) How do scaffolded in class group activities influence students’ perceived problem-solving strategies?

The second research question aims to engage students in active learning group activities with the objective of introducing a structured problem-solving strategy to enhance their skills to tackle complex problems. They also participated in self-reflection activities to provide feedback and insights on the effectiveness of these activities and suggesting potential improvement for future course offerings

Methodology

This course was offered in spring 2025, with an enrollment of 74 students. To understand students' perceived challenges in rigorous thermofluid courses such as heat transfer, students were asked to participate in a self-reflection activity. At the beginning of the term an anonymous background survey was conducted to gather insights into students' experiences and reflection on problem solving strategies. The total response rate was N=51. According to the survey, 51% of students reported they had taken one or no prior courses involving problem solving in heat transfer or related topics. The prerequisite for the heat transfer course are introductory and advanced fluid mechanics, which themselves require prior completion of a thermodynamics course. However, the survey results suggest that a significant number of students perceive the thermodynamics course as largely irrelevant to the content of heat transfer. Also, 47% reported either being unfamiliar with or no prior exposure to structured approaches to problem solving in engineering courses.

Students also asked what challenges they face in problem-solving? The thematic analysis in Figure (1) shows students' responses to an open-ended question on their perception of the most significant challenges for problem solving. The thematic analysis of students' responses shows that starting a problem, such as deciding the first step and applying an organized problem-solving strategy is the most repeated theme (with frequency of n=16). The second theme (with frequency n=15) involved choosing the appropriate equation and method to map theory to calculations, which may indicate knowledge gaps in students' conceptual understanding. Students also struggled with using the information given in problem statements, translating it into assumptions and usable equations when solving complex problems. Finally, some students mentioned that visualizing problems were challenging, and for others, handling units and derivations presented an additional bottleneck which could also highlight students' prior knowledge gaps.

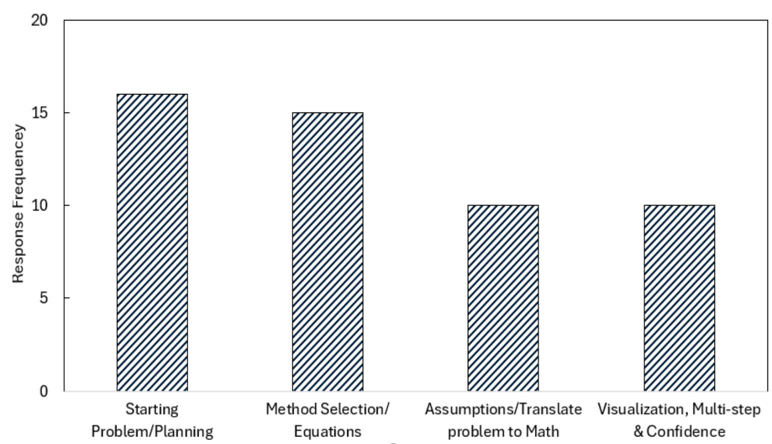

Figure 1: Students' Reflection on Problem Solving Challenge

In addition, students asked to select all main problem-solving strategies among the suggested methods in the survey. The responses are shown in Figure (2). The main strategies used by students are:

1. Looking for similar example problems to guide my approach (88.2%)
2. Watching tutorial videos or reading additional materials (70.6%)
3. Using a structured framework (e.g., given-find-assumptions-equations-solution) (66.7%)
4. Using online resources (e.g., forums, solution manuals, AI tools) (64.7%)

Among the suggested problem-solving strategies, only 45% of students reported using a scaffolding approach to break complex problems into smaller, manageable steps. Given the critical role of this skill in solving complex problems, the in-class scaffolded activities were proposed to reduce the cognitive load and enhance students' learning.

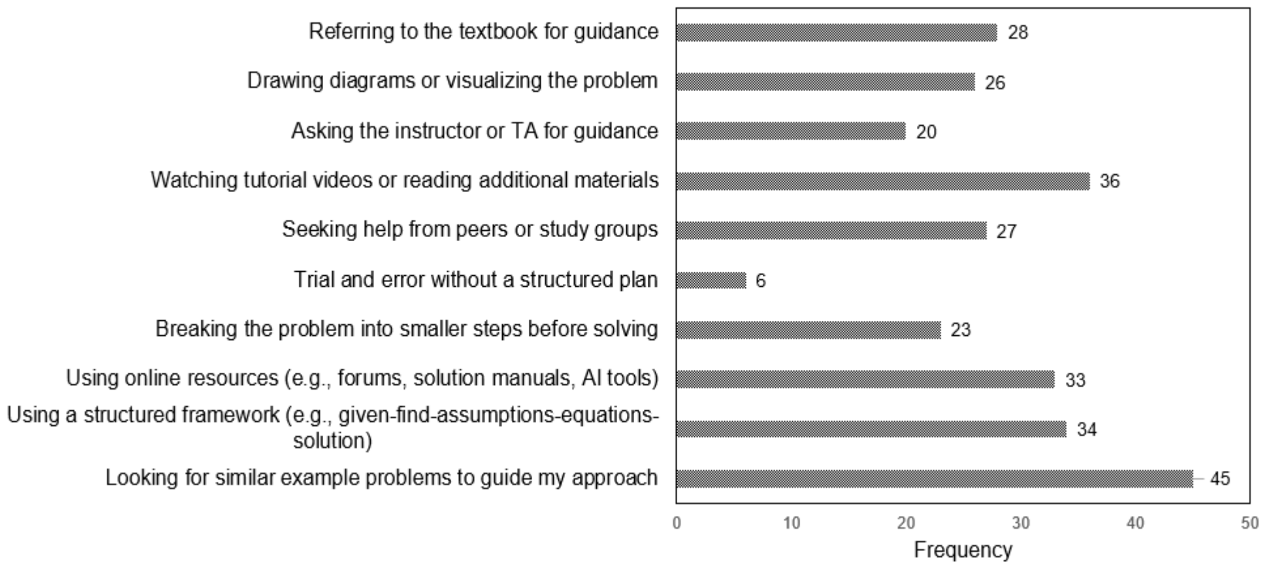

Figure 2: Main problem-solving strategies used by students

Scaffolded Activities

Students require strong conceptual understanding in heat transfer courses in order to make appropriate assumptions and apply differential equations to relate mathematical models to physical phenomena. To support the development of these problem-solving skills, students engaged in three scaffolded in-class group activities throughout the course.

As shown in Table (1) each activity was broken into multiple steps to guide students' problem solving. The activities started with a general conceptual question to encourage "big picture" thinking and having them reflect on the validity of their assumptions. They then followed scaffolded guidance to integrate appropriate equations to solve the problem. Whenever needed, targeted hints were included throughout the activity to address common points of confusion.

In addition, at the end of first and third activities, students responded to short reflection surveys about their experience and provided suggestions for improvement.

Table 1: Scaffolded in-class activities in a Heat Transfer course

I. Week 3, Aluminum wall Cooling	
Problem Description: Estimate the cooling time of a flat aluminum plate from 50°C to 30°C in air using two models: (1) lumped-capacitance model and (2) transient heat conduction model, highlighting how assumptions affect results.	
Scaffolded Steps	**Skill Developed**
1. Identify the physics of problem and key dimensionless number.	Conceptual understanding
2. Calculate average heat transfer coefficient.	Analytical reasoning/Quantitative modeling
3. Check Lumped Model validity.	Evaluation of assumptions
4. Compute cooling time for specific ΔT	Formula selection
5. Propose approach for ΔT-dependent h_c.	Planning strategy
II. Week 5, Radiative Heat Transfer in Triangular Duct	
Problem Description: Determine the heat transfer rate by radiation into a long triangular duct and the temperature of the heated surface to maintain a target temperature on an insulated surface, using energy balance calculations.	
Scaffolded Steps	**Skill Developed**
1. Write simplified net heat exchange equation.	Translate problem into equations
2. Calculate emissive power for surfaces 1 & 2.	Quantitative analysis
3. Determine emissive power for surface 3.	Application of boundary conditions
4. Find temperature of surface 3.	Translating calculations into physical results
5. Calculate net heat transfer for surface 3.	Integration of results, verification of solution
III. Week 9, Furnace Wall Transient Conduction	
Problem Description: Predict the temperature of the outer surface of a brick wall in a furnace over time using transient heat conduction models with one surface held at a constant high temperature and the other insulated.	
Scaffolded Steps	**Skill Developed**
1. Label initial temperature and boundary conditions.	Conceptual understanding
2. Justify half-slab approximation.	Evaluation of assumptions, physical reasoning
3. Calculate thermal diffusivity and Fourier number.	Quantitative reasoning, dimensional analysis
4. Determine number of terms needed in series solution.	Analytical judgment, series convergence
5. Calculate outer-surface temperature.	Application of series solution

Students' Reflection on Activities I and III

Students completed reflection surveys after the first (Week 3) and third (Week 9) scaffolded activities. A total of 46 students completed the survey after the first activity, while 27 students completed the survey for the third activity. The reflection questions collected students' perspectives on the following aspects:
(a) the effectiveness of the activity in guiding their thinking,
(b) which components of the activity most supported their understanding of the topic,
(c) which components were confusing or challenging

(d) group strategies used to resolve difficulties during problem solving, along with students' self-reported ratings of group collaboration.

Thematic analysis was performed to find trends in students' responses for the proposed activities. For both surveys students consistently emphasized the effectiveness of the method in guiding their thought process. Students also expressed stepwise guidance, hints, and conceptual focus as the most helpful aspect of both activities. They reported equations were effective only when paired with clear conceptual understanding. Some of the representative comments have been shown here.

"The first few questions helped me understand what each part of the equation does."

"The step-by-step guidance made the problem more digestible and helped me avoid getting stuck at the beginning."

"The multiple-choice questions helped me think conceptually about how changing a parameter affects the outcome, instead of just plugging in numbers."

The confusion points for the two activities were different. In the first activity, students reported confusion mostly in later steps where they needed to combine several concepts to solve the problem, while for the third activity, the confusion point was how to set up the problem in early steps and how to use variables to build the model. The consistent confusion themes for both activities were the need for guidance to link equation to physical interpretation, how to do mathematical processes, and the need for clear instruction when multiple variables and steps are involved. A few examples of student comments are shown here.

"Formulas got me confused because I forgot certain scenarios to apply them in."

"We got stuck on step 2 deciding how to approach the integral."

"Initially setting up the inequality since I had no example to go off of."

"What the different T variables represented."

Across both activities, peer collaboration was the main strategy for maintaining progress. Students also consulted their notes or textbook and tried multiple approaches to move forward. However, for Activity 1, they relied more on notes and instructor guidance, since the content was conceptually more challenging, involving derivations. For Activity 2, students reported that peer discussion and trial-and-error assumptions were their primary strategies for handling procedural tasks and variable interpretation. Selected student comments are presented below.

"We got stuck and confused many times. We moved forward by trying different approaches and listening to each other's approaches."

"We asked other teams and looked at notes."

It should be noted that the response rate for these two activities decreases from 46 students (Week 3) to 27 students (Week 9). This could be due to several factors including reduced student engagement during the weeks preceding the final exam as students focus on other courses, the low-stake nature of the class activities that did not significantly impact grades, or simply the limited participation in the course reflection survey due to its voluntary and anonymous nature.

Student Perspectives on More Scaffolded Activities and Adopting Flipped Classroom

To make informed decisions on how to revise this work in the future iteration of course and explore ways to free up class time for more similar activities, students were asked in an end-of-term survey about their thoughts on adopting a combined flipped model and including more scaffolded practice during lecture. Students generally expressed support for increased guided problem-solving during class. Many reported that working in teams helped them understand the material and figure out how to approach challenging questions.

However, opinions on a flipped classroom adoption were mixed. While some students saw value in short, pre-recorded lectures to allow more time for class activities, others expressed concerns about the additional workload, scheduling conflicts, and difficulty maintaining engagement outside of class. Several students highlighted the importance of providing accompanying notes and textbook references along with the videos. Overall, students emphasized that interactive discussion and in-class problem solving remain a key component of their learning experience.

Future work

Scaffolded activities have been used in the heat transfer course to support student problem-solving and reduce cognitive load. Reflections suggest that scaffolded design and team collaboration helps students discuss concepts, assumptions, and strategies effectively. In the next step, the activities will be revised to gradually reduce scaffolding as students gain mastery to support independent problem-solving. A slight adoption of a flipped model may also integrated to allow for more in class activities of this type. Future work could also explore using reflections to track problem-solving strategies and investigating how different group dynamics affect learning and engagement.

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