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Exploring Conceptual Understanding in Heat Transfer: A Qualitative Analysis

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Exploring Conceptual Understanding in Heat Transfer: A Qualitative Analysis

Abstract

Research shows that engineering students struggle to understand concepts in certain core engineering courses such as heat transfer. Students may be able to solve specific problems by following a sequence of steps (referred to a procedural knowledge), but often lack conceptual knowledge, or deep understanding of concepts and the relationships among concepts. Yet it is this conceptual knowledge that can help students transition from novice to expert in a domain. Ideally, procedural and conceptual knowledge are developed in an iterative process where increases in one type of knowledge lead to increases in the other. To determine the extent to which students balance the development of conceptual and procedural knowledge, prior studies examined the way in which students described their approaches to learning in statics courses. The current research expands on this prior work by examining the relationship between students' approaches to learning and their conceptual understanding of heat transfer material. We compared students in two sections of a heat transfer course: the experimental section had a hands-on workshop in addition to lectures, and the control section consisted of lectures only.

As part of a larger study examining student motivation and conceptual change, a multiple case study approach was utilized. Semi-structured interviews were conducted with students towards the end of a semester-long heat transfer course. Interviews were coded to identify 1) learning approaches focused on developing conceptual or procedural knowledge, and 2) students' conceptual knowledge of the heat transfer material.

All participants in the study discussed learning approaches that were aimed at developing procedural knowledge. Some students discussed balanced learning approaches focused on developing both conceptual and procedural knowledge, while other students primarily discussed approaches focused on developing procedural knowledge. We compared the learning approaches and the conceptual knowledge of students who were in the workshop section to students who were not. When taking into account students' learning styles, students in the workshop demonstrated more conceptual knowledge than those students who had similar learning approaches but were not in the workshop section. Additionally, the students in the workshop section were able to define terms more conceptually, while the students who were not in the workshop struggled to define the terms.

Introduction

Within engineering education (and STEM fields in general), we place a high priority on understanding concepts and repairing misconceptions[1]–[4]. However, engineering students struggle to understand the concepts in certain courses, such as thermal science[5] which includes heat transfer. Research shows that both conceptual and procedural knowledge are important in developing conceptual understanding[1], [6]. In this study, we examine the relationship between students' learning approaches and their conceptual understanding of heat transfer material.

Studies have examined the impact of instructional strategies, such as hands-on workshops, on students' conceptual understanding. Cirenza, Diller, and Williams [7] assessed the effects of challenge-based instruction (CBI) on students' conceptual understanding of heat transfer concepts. CBI pedagogy was designed to promote discovery and the connections between concepts and physical phenomena that is observed and measured. The authors found that students who participated in a hands-on CBI workshop (experimental group) scored significantly higher on a concept inventory test that assessed students' conceptual knowledge than those students who did not participate in the CBI workshop (control group). However, when comparing test and quiz scores with overall course grades, the authors found no statistically significant differences between the experimental and control groups. Cirenza et al. recommended additional research in evaluating students' conceptual understanding of heat transfer concepts. In-depth examination into students' thought processes is needed to better understand students' understanding of these topics.

Other studies found that learning approaches may be an important factor when determining the impact of instructional strategies. Venters et al. [3] examined the impact of learning approaches on students' conceptual understanding and showed that the way in which students describe their learning approaches can be used to determine to what extent students balanced the development of both conceptual and procedural knowledge. This balance of conceptual and procedural knowledge can help students solve problems. Venters et al. used interview data to place students on a continuum ranging from procedural-focused to conceptual-focused based on the learning approaches described by the students. These results indicate that learning approach may be a factor influencing conceptual understanding and the impact of instructional strategies.

The current study expands on this prior work and examines the relationship between a CBI workshop and students' conceptual understanding when considering students' learning approaches. By examining students' learning approaches and their conceptual understanding, we can better understand the relationship between strategies designed to promote understanding, such as the incorporation of CBI workshops, and students' understanding of the material.

In particular, this paper examines the following research questions:

- What is the relationship between students' learning approaches and their conceptual understanding in a heat transfer course?
- How does a CBI heat transfer workshop relate to students' conceptual understanding when taking into account students' learning approaches?

To answer these questions, a qualitative case study was conducted using interviews of students who were taking a heat transfer course. By identifying learning approaches and conceptual understanding for students who did and did not participate in a CBI workshop, we examined the relationships between learning approaches, conceptual understanding, and a CBI workshop.

Theoretical framework

Our research is grounded in the cognitive perspective of learning. In the cognitive perspective, knowledge consists of having mental models based on key concepts, and these models are essential for solving problems [8]. Mental models are mental representations of concepts and the relationships between concepts. Within this perspective, novices are characterized as either lacking these mental models or having models that are not well developed [8]. In contrast, experts have mental models and group knowledge in a way that reflects a deep understanding of the material [9]. Therefore relevant information can be retrieved even in novel situations.

Often, students are novices who are able to solve specific problems by following a sequence of steps (referred to a procedural knowledge[1]), but lack conceptual knowledge, or deep understanding of concepts and the relationships between concepts. The definitions for procedural and conceptual knowledge used in this study are shown in Table 1. The development of conceptual knowledge can help students transition from novice to expert by helping students represent the problem, select between different problem approaches (procedures), and apply procedures to novel problems [1]. This development of conceptual knowledge can lead to improvements in procedural knowledge in an iterative process [1] that can help students develop mental models based on central concepts and help students solve new and different problems.

Table 1: Definitions of Procedural and Conceptual Knowledge

Type of Knowledge	Definition
Procedural Knowledge	“the ability to execute action sequences to solve problems” (p. 346) [1]
Conceptual Knowledge	“implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain” (p. 346) [1]

Methods

We used a qualitative case study approach with a quasi-experimental design. Qualitative research aims to examine a particular context in detail, rather than generalizing to all contexts [10]. Qualitative methods allow us to examine students’ learning approaches and conceptual knowledge in more depth and further examine and expand on the results of prior studies. Specifically, a case study methodology was selected to allow for an in-depth examination [11] of the relationship between students’ learning approaches, a CBI workshop, and students’ conceptual understanding in the heat transfer course. We used a cross-case analysis with a variable-oriented approach [12] to examine students’ learning approaches and their conceptual understanding of heat transfer questions. Each student represented a case. We analyzed data within cases and then looked across cases for patterns to better understand patterns and relationships between learning approaches, participation in a CBI workshop, and conceptual understanding.

Settings and participants

We conducted this study at a large, public university in the mid-Atlantic region. We focused on two sections of a heat transfer course. Both sections were taught by the same instructor and both sections met three times a week for 50 minutes. However, students in the experimental section participated in six CBI workshops throughout the semester (Table 2). Each workshop lasted approximately one hour. Students in the experimental section were assigned one less textbook homework problem during the weeks when workshops were held. This was to balance the workload for the two sections of the course. Therefore, it was assumed that students in both sections were spending approximately the same amount of time on average for the course.

Table 2: Groups involved in the study

Control Section	**Experimental Section**
Lectures 3x/week	Lectures 3x/week
Additional homework problems	CBI workshop

The workshops used a CBI pedagogy, as described in Cirenza, Diller, and Williams[7]. Consistent with CBI, students began the workshop by generating ideas related to a challenge question. The challenge question included a description of a real world problem that a practicing engineer might experience. The students had to determine a solution or recommendation to address the challenge question. An example challenge question is shown in Table 3. Students were provided background information on the challenge and sample data from an experimental setup. The experimental setup was available in the lab so that students could see and feel what was happening, but the data from such an experiment was provided. Students identified relevant equations, performed calculations, and answered the challenge question. At the conclusion of the workshop, students reflected on the concepts covered.

Towards the end of the spring semester, we interviewed students who participated in the workshop and students who did not. To recruit participants, we sent an email via the professor to all students in both sections of the course. Eleven students responded to the recruitment email, and these eleven students participated in in-person interviews. Five participants were in the section that did not have a workshop (control group) and six participants were in the section that did have a workshop (experimental group). However, three out of the eleven students interviewed were not asked all of the interview questions. Therefore, the following discussion will focus on the eight students interviewed who were asked all of the questions from the interview protocol. The eight participants were split evenly with four who were in the workshop section and four who were not. This sample size allows us to investigate the learning approaches and conceptual understanding of participants in the heat transfer course in greater depth.

Table 3. Example challenge context and question from a CBI heat transfer workshop

Context and Challenge:	Metal buildings are typically made with steel beams with layers of thermal insulation placed in between in assembling the roofs and walls. The insulation works well except where the beams are, which act like thermal conduits. Some manufacturers cover the beams and insulation with a layer of cloth. There is a dispute whether this affects the thermal performance of the walls and roofs. You are to resolve this dispute. Does the cloth matter or not? You need to justify your response.
Challenge Question:	What effect does adding cloth have on metal vs. insulation?
Workshop Objectives:	Understand the difference between parallel and series thermal resistances Understand the difference between heat, energy, and temperature Understand the difference between heat flux and temperature measurements

Data collection and analysis

We conducted semi-structured interviews of participants. The first section of the interview contained questions about learning approaches used by the student during the heat transfer course. Answers to these questions were used to determine students' learning approaches. The second section of the interview contained conceptual understanding questions where students were asked to discuss their thought processes while solving heat transfer questions. This section was used to determine students' conceptual knowledge. Interviews were audio-recorded and later transcribed. Learning approaches used by the students (Table 4) were identified using open coding, a process where codes and categories are identified in an emergent process [13]. Using the software MAXQDA, interview segments that described student's learning approaches were marked and coded. The learning approaches were identified as either conceptual or procedural, depending on whether the strategy was focused on developing conceptual or procedural knowledge using the definitions in Table 1. Concurrently with the coding process, codes were grouped into categories. Once no new codes or categories emerged from the data, all interviews were recoded.

After all interviews were recoded, the learning approaches for each participant were rated. Ratings consisted of high, medium, low, and not present. High ratings indicated that that learning strategy was a primary learning strategy. The approaches rated as high were identified by the student as being a strategy for most course activities or were indicated by the student as being an important learning strategy. Low ratings indicated that the learning strategy was mentioned in the interview, but was not a primary learning strategy. The approaches rated as low were identified by the student as being a minimal part of one or two course activities. Approaches rated as not present were not identified during the interview.

Table 4: Learning approaches focused on developing procedural and conceptual knowledge.

Type of Knowledge	**Learning Approaches**	**Definitions**
Procedural	Practice	Student indicates that they do (work) problems.
	Problem Approach	Student indicates that they think about the approach to a problem or how to approach/solve problems.
	Follow Procedure	Student indicates following a set of steps to solve problems.
	Relate to Similar Example	Student indicates that they find and/or use a similar problem when working problems.
	Linear Organization	Student indicates that they organize information according to someone else's organizational scheme (ie, organize by book section, by instructor's notes, etc).
	Memorization	Student indicates a need to memorize information.
Conceptual	Understanding	Student indicates that they try to better comprehend (understand) the material and /or concepts.
	Why procedures work	Student indicates an attempt to understand why procedures work.
	Relate information	Student indicates relating course material to other material covered in the same course, a different course, or the real world.
	Organization	Student indicates that they make an effort to organize the information in a way that is meaningful for them.
	Identify gaps in knowledge	Student indicates that they identify information that is/was missing.

An example of a student's learning strategies identified during an interview can be seen in Figure 1. In this example, the student discussed eight out of the eleven identified learning strategies throughout the interview. Some learning strategies, such as practicing problems and trying to understand why procedures worked, were discussed as a primary learning strategy (high). Other learning strategies, such as relating a problem to a similar example problem, were identified during the course of the interview but were not primary learning strategies (low). In this example, memorization and identifying gaps in knowledge were not identified during the interview.

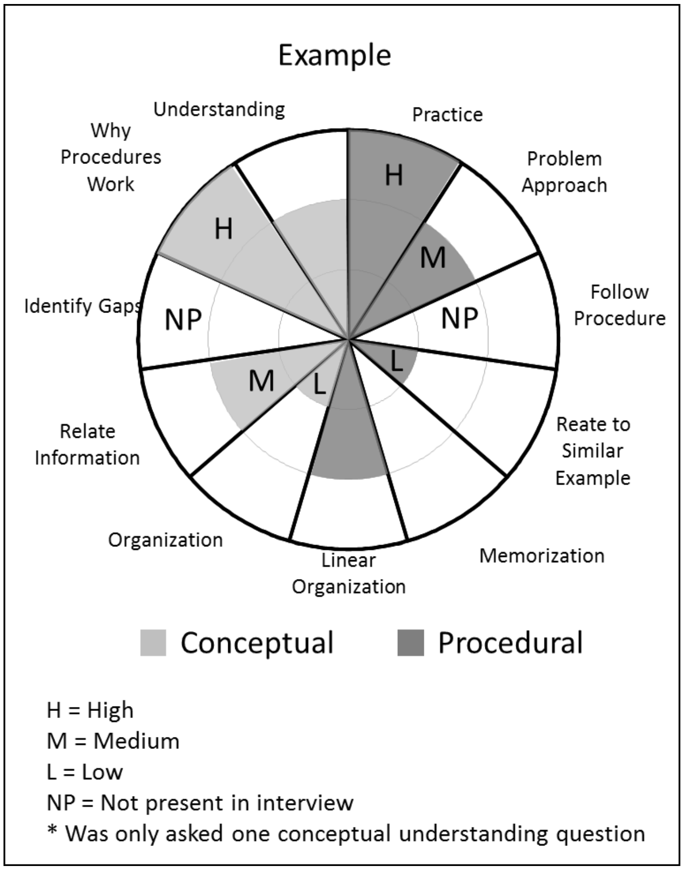

Figure 1. Example of learning approaches identified during participant interviews. For each student, learning strategies were rated as high (H), medium (M), low (L), or not present (NP).

We analyzed the conceptual understanding section of the interviews to determine students' conceptual understanding of the course material. The conceptual understanding section included questions related to the definitions of terms (definitions), heat transfer scenarios where students had to identify specific aspects of the scenario and then compare two scenarios (scenarios), and a heat transfer problem where students had to explain what would happen to a system when one aspect changed (problem).

Student answers to the questions in the conceptual understanding section of the interview were also coded and analyzed. We worked with the instructor and graduate teaching assistant for the heat transfer course to analyze the heat transfer questions. We looked for correct answers to the questions and also examined the reasoning and explanations provided by the students. Student answers and their reasoning were coded as either correct or incorrect. Students' responses for each section in the conceptual understanding portion of the interview (definition, scenarios, problem) were ranked from low to high conceptual knowledge based on whether the students answered the questions correctly and provided correct reasoning. An example is shown in Figure 2. In this example, the student demonstrated high conceptual knowledge when answering the problem, but demonstrated lower conceptual knowledge when answering questions about the heat transfer scenarios. When defining terms, this example student correctly defined the majority of the terms.

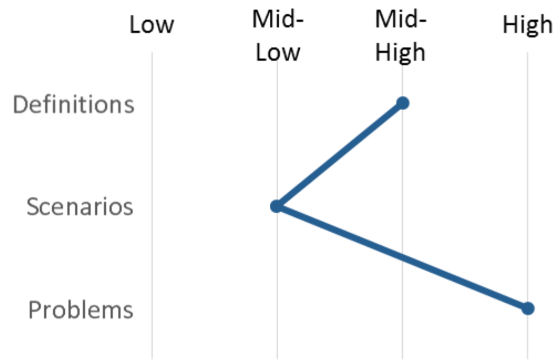

Figure 2. Example of conceptual knowledge classification identified during interviews.

Trustworthiness

Researcher triangulation was conducted to ensure trustworthiness of the findings. Researcher triangulation is the use of multiple investigators to enhance the trustworthiness of the findings [14]. While coding the learning approaches, multiple researchers coded portions of the interviews and compared the coded segments helping to refine the definitions for the learning approaches. In addition, we coded and recoded the interview transcripts after a period of time, which is a method used to ensure trustworthiness [14]. Researchers worked with both the graduate teaching assistant for the heat transfer workshop and the professor who taught the heat transfer course to enhance the trustworthiness of the analysis of the conceptual understanding questions. The researcher also attended a majority of the workshops and observed student interaction during the workshop to better understand the study setting.

Preliminary results

This study examines relationships between learning approaches, participation in a CBI workshop, and conceptual understanding. Preliminary results indicate that students' learning approaches relate to their conceptual understanding of the heat transfer material. When comparing students who took the workshop to those who did not, we found that those students in the workshop section were able to define heat transfer terms more conceptually, while those who did not participate in the workshop struggled to define the terms and often attempted to define terms using units. We also found that, for students with balanced learning approaches focused on developing both conceptual and procedural knowledge and students with learning approaches focused primarily on developing procedural knowledge, the students in the workshop had more conceptual understanding than those students who had similar learning approaches but were not in the workshop section.

Identification of Learning Approaches

In describing their approaches to learning in the heat transfer course, students discussed a variety of learning approaches. Some students discussed balanced learning approaches aimed at developing both conceptual and procedural knowledge while other students primarily discussed approaches focused on developing procedural knowledge. For example, Greg (workshop section) and Robert (control section) discussed a balance of learning approaches and incorporated learning approaches aimed at developing both procedural and conceptual knowledge. On the other hand, Justin (workshop section), Hunter (control section), and Chelsea (control section) primarily discussed learning approaches focused on developing procedural knowledge, such as practicing problems, following a procedure when solving problems, and organizing information in a linear fashion. All other students incorporated learning approaches aimed at developing both procedural and conceptual knowledge to varying degrees. The learning approaches for students who participated in the workshop are shown in Figure 3, and the learning approaches for students who did not participate in the workshop are shown in Figure 4. Since all students discussed learning approaches focused on developing procedural knowledge, such as practicing problems, no students focused exclusively or even primarily on developing conceptual knowledge.

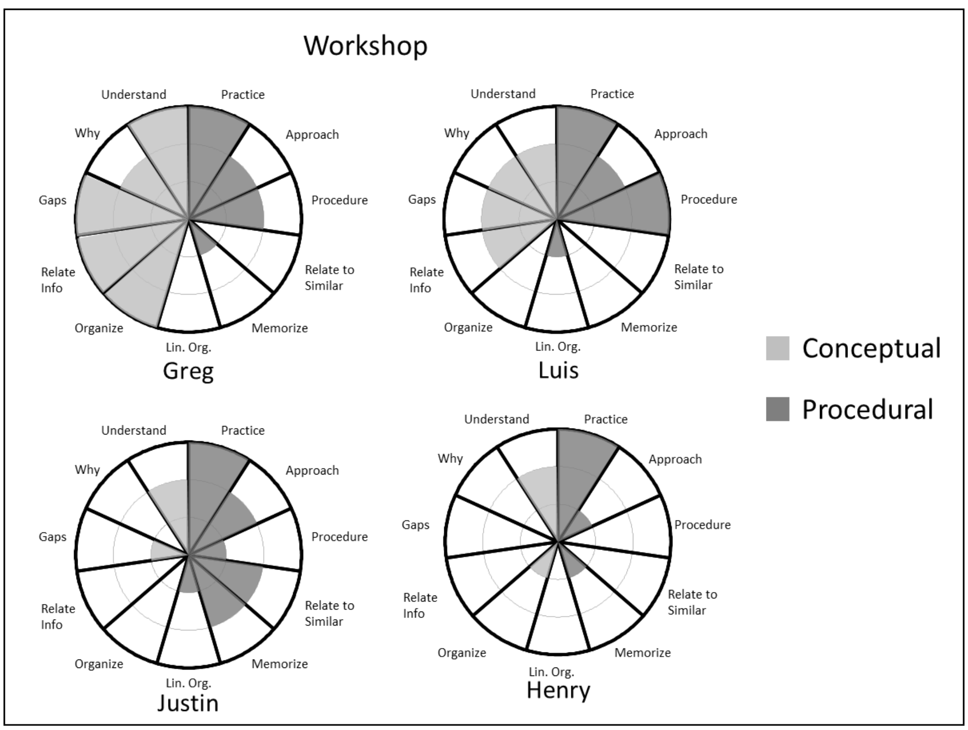

Figure 3. Learning approaches for students who participated in the workshop.

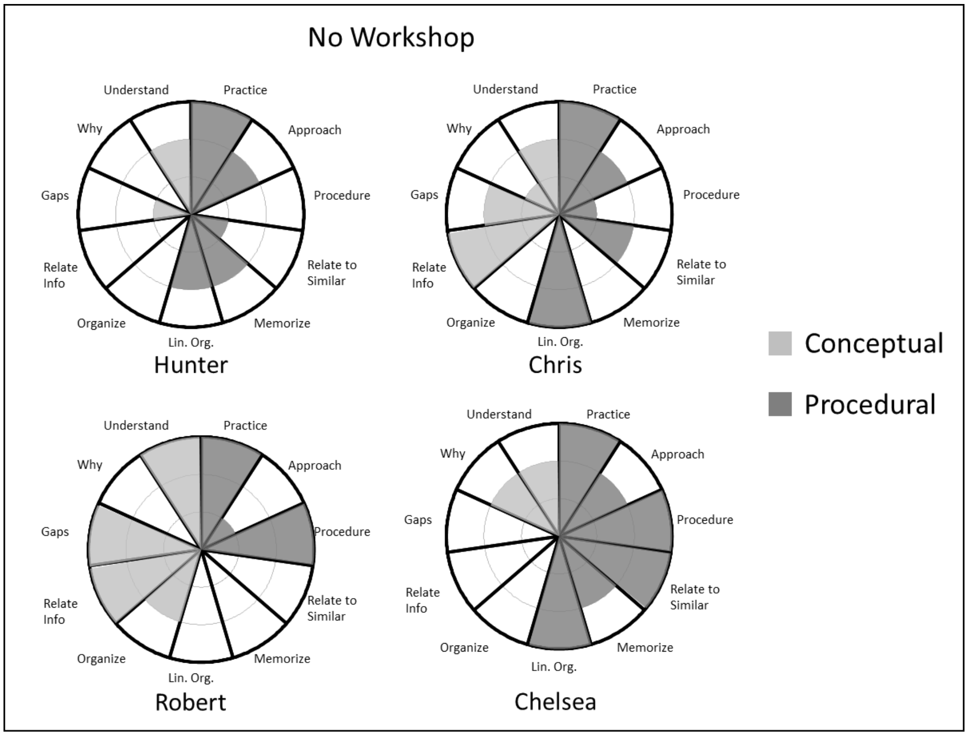

Figure 4. Learning approaches for students who did not participate in the workshop

Greg discussed learning approaches that were balanced and focused on developing both procedural and conceptual knowledge. While he discussed working problems and following procedures when solving problems, Greg also discussed organizing the information in a meaningful way by making a list of all the topics in the class and identifying the different aspects related to each topic. This list then helped him identify gaps in his own knowledge.

> "What [studying] usually means to me is that I will write down a list of everything that we're supposed to have learned, like a topic. I guess for the second test we had in this class, I wrote down internal flow, external flow, and there was one more, I don't remember exactly what it was. It's just the three topics and then I'd write down everything I know about each of those things and then compare that to the notes that I've taken, and if there's anything missing, use that to fill in the gaps."

This demonstrates that Greg organized information in a meaningful way around central concepts which is a component of conceptual understanding. Greg emphasized that this organization of information into study guides was meaningful for him, but was not necessarily organized in a way that was meaningful for others.

> "I think the cool thing about [my study guide] is that it's not that useful for anyone else. I gave it to some of my friends in a younger grade and I don't think they used it, just because the act of creating it is what's important and then it's a good reference for you,

> but it doesn't really make that much sense to anyone else because it's the way you think about it, it's the order you think about it, and if it doesn't match someone else's, then it's not going to be that helpful."

These learning approaches indicated that Greg used approaches, such as organization of course topics, which were focused on developing conceptual knowledge in addition to using learning approaches to develop procedural knowledge, such as practicing problems.

Another student, Chelsea, primarily discussed learning approaches that focused on developing procedural knowledge. Although she briefly discussed trying to identify why procedures work and using resources to better understand the course material, many of her learning approaches focused on determining the correct procedure to follow. For example, she stated that she desired to know the order of steps for each type of problem and wrote out the steps for various problems when studying.

> "For some types of problems it helps me to write out the steps of what you have to do. I really enjoy when teachers in class will be like, 'Oh, well for external flow problems you have to do A, B, C, D, E', and that really helps me because my brain has to be organized. I have to know exactly what to do next."

This indicates that Chelsea wanted an exact procedure to follow for each type of problem. She also stated that the goal of studying was to practice enough problems before the test so that she would have seen all variations of the problems.

> "Well, I think the goal is to have done so many problems so that when I get on a test and I've ran into something like that, I am able to work through it. The goal is to work through as many problems so that you come to as many roadblocks as you can, so you can overcome then, so that on the test, you're like, 'Oh, I already did this. I already understand how to get around this.'"

These learning approaches indicated that Chelsea used learning approaches that focused primarily on developing procedural knowledge. She focused primarily on the procedures to follow and did not focus on the concepts in the problems which would allow her to solve new problems. These two examples highlight the range of students' learning approaches in the heat transfer course ranging from balanced approaches to procedural-focused approaches.

Identification of Conceptual Understanding

We identified students' conceptual knowledge based on the conceptual understanding section of the interview. Students demonstrated a range of conceptual knowledge ranging from low to high conceptual knowledge for the definitions, scenarios, and problems. The conceptual knowledge for students who participated in the workshop are shown in Figure 5, while the conceptual knowledge for those who did not participate in the workshop are shown in Figure 6.

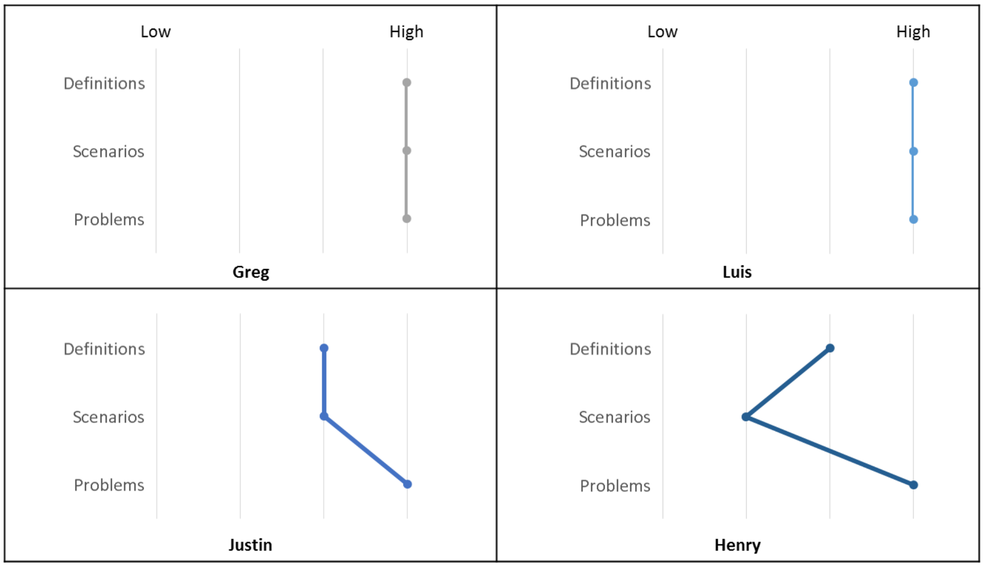

Figure 5. Conceptual knowledge of students who participated in the workshop.

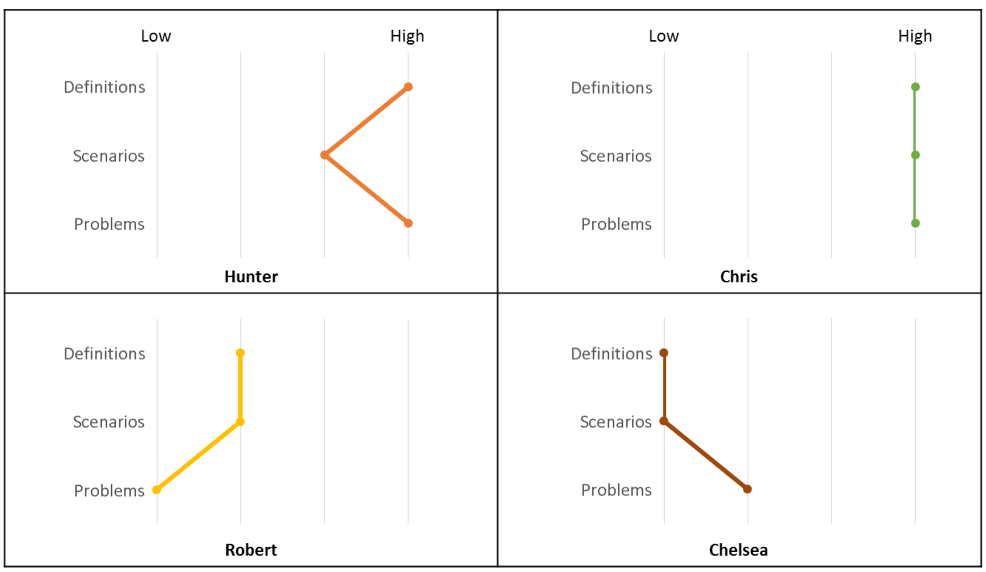

Figure 6. Conceptual knowledge of students who did not participate in the workshop.

Students who demonstrated high conceptual knowledge of heat transfer terms defined the terms conceptually, describing the relationships between terms. For example, Hunter said:

> “Temperature is just a way to measure internal energy. Maybe not necessarily internal energy but it's a way to measure the energy that is stored in an object. Heat transfer is the movement of that energy from one object to another.”

Students who demonstrated low conceptual knowledge when defining terms either defined the term using units (“Temperature, shoot. How do you define temperature? Kelvin, Celsius, or what's the other one? Fahrenheit”), or did not answer the question correctly.

Students who demonstrated high conceptual knowledge when answering the scenario questions were able to determine the modes of heat transfer for the specific scenario and describe whether or not the system was at steady state and in thermal equilibrium. For example, when identifying the modes of heat transfer in the scenario where food is heated in an oven, Chris identified the modes of heat transfer and considered the specific problem presented instead of simply listing the various modes of heat transfer.

> “Convection oven, so you got convection, you got conduction from the ... You have conduction in there. You have some radiation too. Obviously, radiation won't ... Well, I suppose so. It would be pretty significant.”

On the other hand, students who demonstrated lower conceptual knowledge when answering the scenario questions did not answer these questions completely or accurately, or made general statements that were not specific to the scenario. For example, Henry demonstrated lower conceptual understanding because he made general statements that radiation is typically less than other modes of heat transfer without considering the effect of radiation in the specific problem. He did not consider the specific impact that radiation has when considering how an oven works.

> “And you'd have radiation, but I'm not sure radiation would be as big of a player as convection…My understanding is that radiation is always present. However, when convection and radiation are present, convection usually outweighs radiation.”

Students who demonstrated high conceptual knowledge when answering the final heat transfer problem not only answered the question correctly but determined the correct energy balance. Students who demonstrated low conceptual knowledge when answering the heat transfer problem either were not able to answer the question correctly or did not accurately capture the energy balance.

Relationship between Learning Approaches and Conceptual Understanding

We examined the relationship between students’ learning approaches and their conceptual knowledge of the heat transfer material. Preliminary results indicate that balanced learning approaches may relate to higher conceptual knowledge in a heat transfer course. In this section, we examined the conceptual knowledge and learning approaches of the four workshop participants to examine the relationship between learning approaches and conceptual understanding.

Henry and Justin both described learning approaches that focused on developing procedural knowledge (Figure 3) and both demonstrated lower conceptual knowledge than the other workshop participants who were interviewed (Figure 5). Greg and Luis, the other workshop participants, both described learning approaches that were more balanced and demonstrated higher conceptual knowledge. This indicates a potential relationship between learning approaches and conceptual knowledge.

During the conceptual understanding portion of the interview, Henry emphasized the importance he placed on procedural knowledge by acknowledging that if he got the answers wrong conceptually, those errors would be reflected in the equations when solving the problem. For example, when asked to identify the source and the sink in the scenario where a person is sitting in a climate controlled room, Henry replied:

> "Which one is the source, which one's the sink? I have two theories. Is it going from hot to cold or is it what's supplying the heat? Because my body temperature is changing based on the room temperature. I feel like [the room] would be the source and I would be the sink but then again I am releasing that heat. I guess it kind of depends on how you interpret it. In the end in terms of if I want to find heat transfer it would just be a negative and if I did it from the cold to the warm it would be the negative."

Henry indicated that if he misunderstood a concept, the equations would reflect that misunderstanding. This demonstrates that Henry relied on the equations, the procedural knowledge, and was less focused on the conceptual knowledge.

Greg, on the other hand, demonstrated high conceptual knowledge when answering questions about the heat transfer scenarios. He thought about the questions conceptually and his answers were specific to the problem presented. For example, when asked about the modes of heat transfer in the case where a person is sitting in a climate controlled room, Greg considered the specifics of this case to determine the heat transfer that was occurring.

> "There'd be a radiant heat transfer from your skin and then a convection heat transfer as well, just natural convection off your skin. Then I guess if you're sitting on something and you haven't been sitting there for very long, there'd be some conduction into whatever you're sitting on."

This highlights that Greg thought about the problem conceptually by considering the specific situation and using his knowledge of convection, conduction, and radiation to determine the modes of heat transfer in the specific scenario.

Henry, whose learning approaches primarily focused on developing procedural knowledge, discussed the importance of equations and did not discuss answers that were specific to the questions being asked. Greg, whose learning approaches were more balanced, considered the specifics of each case and demonstrated more conceptual understanding of the material. This indicates that balanced learning approaches may relate to higher conceptual knowledge.

Relationship between Workshops and Conceptual Understanding

After determining students learning approaches and examining the relationship between students' conceptual understanding and their learning approaches, we examined the impact that a CBI workshop has on students' conceptual understanding when their learning approaches are also considered. We first compared the conceptual knowledge of those students who participated in the workshop with those who did not. We also compared students who participated in the workshop to students with similar learning approaches who did not participate in the workshop. We aimed to identify differences in conceptual understanding due to the workshop.

When comparing the conceptual knowledge of students who participated in the workshop to those who did not, we found that students who participated in the workshops gave definitions that were more conceptual. Three out of the four students who did not participate in the heat transfer workshop attempted to define the heat transfer terms by stating the units for each as opposed to defining the terms conceptually. For example, when asked to define temperature, Robert, who did not participate in the workshop, defined terms in the following way:

> "Temperature, shoot. How do you define temperature? Kelvin, Celsius, or what's the other one? Fahrenheit?"

In comparison, Luis, who did participate in the workshop, was able to give more conceptual definitions for these terms.

> "Temperature is the measure of the amount of thermal energy within an object and then internal energy or the measure of that internal energy within an object. Heat transfer is the thermal transfer of that energy from one object to another, whether it's by convection, conduction or radiation."

We also compared students who participated in the workshop to students with similar learning approaches who did not participate in the workshops. Students who participated in the workshops often demonstrated more conceptual understanding than those students who had similar learning approaches but did not participate in the workshop. For example, Greg (workshop) and Robert (control) both discussed learning approaches that were balanced and focused on developing both procedural and conceptual knowledge (Figure 7).

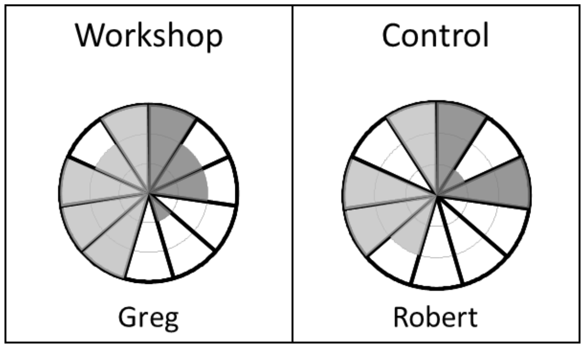

Figure 7. Learning approaches for two students with approaches focused on developing both procedural and conceptual knowledge.

When asked to compare two heat transfer scenarios, Greg compared the two scenarios more conceptually while Robert focused on the differences in temperatures between the two. For the first scenario, we asked students questions about the heat transfer involved in cooking food (a turkey) in the oven. The second scenario asked students to consider the situation where a person sits in a climate controlled room. Greg stated that the fundamental differences between the two scenarios were as follows:

> "I guess with the turkey, the source being external, the outside is going to continue to get hotter than the inside, whereas with the internal generation from your body, the surroundings are big enough relative to the ... and it's climate controlled I guess as well, so you're not affecting the temperature of the surroundings that much, whereas the turkey being in the oven, its temperature is constantly changing."

Robert, on the other hand, focused on the temperatures in the specific problem instead of concepts when identifying the differences between the two scenarios.

> "[The first] one's 70 degrees. Temperature. The other one's at 350. One was really, the source is giving a lot of heat to the sink in the first one. The other one is, I guess it depends on the temperature that it's initially at. The other one is not, the temperature is the main difference."

These statements indicate that while both students used balanced learning approaches aimed at developing both procedural and conceptual knowledge, Greg, who participated in the workshop, provided answers based on his experience that were more conceptual while Robert, who did not participate in the workshop, focused on the specifics of the problem presented.

In addition to comparing two students whose learning approaches were balanced, we compared two students, Justin (workshop) and Chelsea (control), whose learning approaches focused on developing procedural knowledge (Figure 8). While Justin was able to answer the conceptual questions fairly completely, Chelsea confused several concepts and struggled to identify the main concepts in the questions.

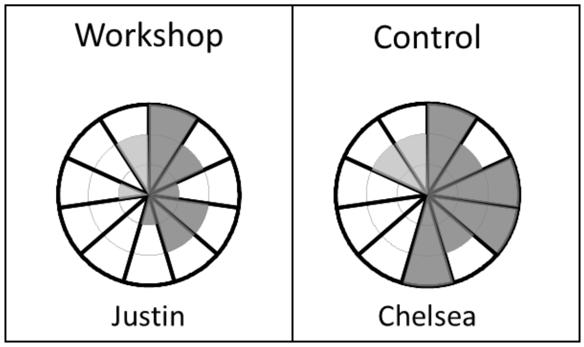

Figure 8. Learning approaches for two students with approaches primarily focused on developing procedural knowledge.

Chelsea was unsure what steady state and thermal equilibrium were and often confused the two when answering the questions. Additionally, when asked to describe the difference between the two scenarios discussed in the interview, Chelsea pointed to differences in the way the question was worded instead of talking about differences in concepts between the two cases.

> "The fundamental difference between the two. For one thing, the wording. In the first one, you say the turkey is in the oven, so you say the cold thing, and then you say the hot thing. In the second one, you say the hot thing and then you say the cold thing. That's a difference."

Students in the workshop were able to define terms more conceptually than students who were not in the workshop. In addition, when comparing students in the workshop to those with similar learning approaches who did not participate in the workshop, workshop participants demonstrated more conceptual knowledge. These results indicate that learning approaches, in addition to strategies that promote conceptual knowledge such as CBI workshops, could impact students' conceptual knowledge.

Limitations

For this study, eleven students in a heat transfer course were interviewed. However, three of the eleven interviews only contained one conceptual understanding question. Therefore, the conceptual understanding section for those three interviews did not contain as much insight into those students' conceptual understanding and were not used in this study. One limitation of the study was that interviews were conducted at the end of the semester and prompted students to reflect on the learning approaches that they used during that semester. These interviews may not have captured all of the learning approaches used by each student. A study conducted throughout an entire semester inquiring about students learning approaches may provide more complete answers regarding the learning approaches used.

Conclusions

In conclusion, this study identified students' learning approaches and their conceptual understanding in a heat transfer course. Preliminary results indicate that students' participation in a CBI heat transfer workshop could relate to more conceptual knowledge of heat transfer concepts, especially when also considering students' learning approaches. When comparing workshop participants to those not in a workshop, workshop participants defined terms more conceptually than participants who did not participate in the workshop. When comparing students who had similar learning strategies, additional differences were identified between workshop participants and those who did not participate in the workshops. Students who participated in the workshop demonstrated more conceptual knowledge compared to students with similar learning approaches who did not participate in the workshop. Future research should further investigate relationships between students' learning approaches and their conceptual understanding of heat transfer topics and the impact of participation in a CBI workshop on students' conceptual understanding.

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