AN ABSTRACT OF THE DISSERTATION OF

Christina Smith for the degree of Doctor of Philosophy in Chemical Engineering presented on July 25, 2017.

Title: Graduate Teaching Assistants (GTAs) in a Studio Learning Environment: Practices, Epistemologies, and Pedagogical Development

Abstract approved:

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Providing transformational learning opportunities for undergraduate students demands changes to teaching practices. In large-enrollment introductory courses, graduate teaching assistants (GTAs) can play an important role in facilitating student learning in small group environments. However GTAs typically are not provided the pedagogical development necessary to utilize them fully in this role. In order to provide GTAs with pedagogical development opportunities, we need an in-depth understanding of GTAs' current teaching practice and how they are making pedagogical decisions, which is based upon their epistemological perspective.

This dissertation presents a comparative case study of two GTAs' practice and epistemology within a junior level thermodynamics Studio. GTA teaching practice is examined through the lens of *ambitious teaching* and focuses on core Studio practices of attending to group dynamics, eliciting student thinking, and providing effective feedback to students. GTAs were video recorded in part to identify the nature of and frequency of these teaching practices. The practices primarily implemented within the Studio environment were directive in nature, which does not align with the Studio

goal to provide students with an opportunity to interactively engage with content, peers, and a facilitator. However, observations of GTA practice does not provide a complete understanding of complex practices.

To further understand pedagogical decisions, this study investigated three expressions of epistemological *resources* and *frames*: the enacted epistemology of GTAs through video observations; the professed epistemology through general teaching and learning pre-, post- interviews; and the reflected epistemology through stimulated recall interviews (SRIs). Results from examining interviews showed that the two GTAs activated a variety of epistemological *resources* and held dissimilar *frames*. The different *frames* are discussed in relation to three core Studio teaching practices and ways pedagogical development would address differences. Following this discussion is a study of the creation, implementation, and reception of a series of pedagogical development seminars situated within a first year, graduate student professional development seminar and concludes with suggestions for future development for GTAs in a Studio learning environment.

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Graduate Teaching Assistants (GTAs) in a Studio Learning Environment: Practices, Epistemologies, and Pedagogical Development

by
Christina Smith

A DISSERTATION

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Presented July 25, 2017
Commencement June 2018

Doctor of Philosophy dissertation of Christina Smith presented on July 25, 2017

APPROVED:

Major Professor, representing Chemical Engineering

Head of the School of Chemical, Biological, and Environmental Engineering

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Christina Smith, Author

ACKNOWLEDGEMENTS

I must thank the divine help that I received throughout this whole process, without which none of this would have been conceived or accomplished.

This dissertation is dedicated to and is a result of, all the strong women who have been a forceful impact and influence in my life. To my mom, sissy, grandma, and shinálí who have instilled in me a love of education, fierce independence, and self-confidence that I can and will achieve anything. Their examples have inspired and continue to inspire me to always keep moving forward.

I also acknowledge and thank my family, who have sustained me through the ebbs and flows of this journey. I want to single out Mr. Cory Thomas who made sure I was fed, taken care of, and who supported my endeavors in other ways.

I would like to thank my advisor Dr. Milo Koretsky for the guidance and opportunities he has provided me over the course of my graduate career as well as all members of my committee: Dr. Devlin Montfort, Dr. Devon Quick, Dr. Jessica Beck, and Dr. Brady Gibbons. I am grateful for and appreciate all those that I have worked with, including: Ann Sitomer, Kathy Quardokus-Fisher, Ying Cao, Debbi Gilbuena, Grace Panther, and Alyssa Deline. I would like to acknowledge any and all other graduate students, faculty members, and administrators who helped support me during this journey.

Yéigo! Ahéhee'.

CONTRIBUTION OF AUTHORS

I designed the studies, collected and analyzed data, and was the primary author for Chapters 2, 3, and 4. I was the facilitator for the graduate student pedagogical development seminar discussed in Chapter 4. Dr. Ann Sitomer assisted with the design in Chapters 2, 3, and 4. She assisted with data analysis, and writing for Chapter 2. Dr. Ann Sitomer also assisted with the data collection, implementation, and writing for the graduate student pedagogical development seminar discussed in Chapter 4. Dr. Ying Cao assisted with the design of the pedagogical development seminar materials discussed in Chapter 4. Dr. Milo Koretsky assisted with data analysis and writing for Chapters 2, 3, and 4.

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1. General Introduction

Providing transformational learning opportunities for undergraduate students demands changes to teaching practices. In large-enrollment introductory courses, graduate teaching assistants (GTAs) play an important role in facilitating student learning in small group environments. However GTAs are not provided the pedagogical development necessary to support them to be effective in their teaching practices. In order to provide GTAs with pedagogical development opportunities, we need an in-depth understanding of GTAs' current teaching practice and how they are making pedagogical decisions, which is based upon their epistemological perspective. As it currently stands, there is limited research on GTA practice and epistemology in engineering, particularly in environments that expect them to implement complex, interactive learning pedagogies such as Studios in engineering (Koretsky, 2015). This dissertation contributes to the current literature around teaching practices and epistemology by focusing on GTAs' epistemology and practice in engineering since they play a significant role in undergraduate students' experience. This dissertation provides an in–depth case study of two engineering GTAs within a second term junior level thermodynamics Studio. It also investigates the creation, implementation, and reception of a series of pedagogical development seminars within a first year graduate student professional development seminar.

Engineering educators implement active learning strategies as a way to engage students and improve their learning gains (Prince, 2004). However, these teaching practices are complex and require time, preparation, and skill to be able to implement them effectively. Windschitl and Barton (2016) provide *ambitious teaching* as a

framework for looking at teaching practices. The authors identify two assumptions that bind cases of successful teaching practice. The first is that the quality of teaching is assessed by the engagement of all learners, which aligns with the goals of an active learning environment. The second is that sustainable improvements in teaching require a "repertoire of practices" that are refined over time. This repertoire of practices should be a part of a larger system of instruction that supports student learning.

At a large research university, Studios are part of a program-level course redesign aimed at increasing the frequency of interactive learning in the classroom. Teaching practices that are important to Studio pedagogy are attending to group dynamics and eliciting student thinking through productive dialogue (Chi, 2009; Fonseca & Chi, 2011; Windschitl & Barton, 2016) and providing effective feedback (Gilbuena et al., 2015). Chapter 2 details the observed practices of two GTAs, Dean and Jeff (pseudonyms), in a junior level thermodynamics Studio course within two structurally different Studios: Studio 1 was conceptually oriented and lab based, whereas Studio 2 was procedurally oriented and required students to engage with mathematical concepts. The nature of and the frequency of the teaching practices of attending to group dynamics, eliciting student thinking, and providing effective feedback are investigated.

Traditionally epistemology has been studied from a unitary perspective (Perry, 1970; Magolda, 1992; Belenky et al., 1986; King & Kitchener, 1994; Kuhn, 1991; Hofer & Pintrich, 1997). Hammer and Elby (2002) provide an alternative framework that takes context into account by identifying resources (e.g. knowledge as fabricated,

knowledge as transmitted) and frames, which are stabilized structures of resources across multiple contexts. Methodologically when investigating epistemology and practice, researchers focus on an "enacted" and "professed" epistemology (Louca et al., 2004; Speer, 2005). Speer (2005) makes an argument that solely focusing on enacted and professed epistemology does not capture the nuances of the decisions being made within the classroom. She suggests using stimulated recall interviews (SRIs) to better understand the connection between epistemology and practice and to contextualize in-the-moment decisions instructors make. Chapter 3 builds on the work in Chapter 2 by investigating the enacted, professed, and reflected epistemological resources and frames (Hammer & Elby, 2002) of Dean and Jeff using SRIs. Dean and Jeff's resources and frames are addressed within the practices of attending to group dynamics, eliciting student thinking, and providing effective feedback.

Chapter 4 discusses the creation, implementation, and reception of a series of pedagogical workshops situated within a professional development seminar that all first year graduate students in an engineering school are required to take. These pedagogical workshops were created and implemented in an effort to "integrate researcher knowledge, practitioner experience, and new institutional structure for pedagogical experimentation" (Windschitl & Barton, 2016, p.1100) as part of the program level course redesign that includes Studios. The goals, seminar topics, main resources, and activities for the pedagogical development seminars are discussed. A survey was administered to graduate students to assess the contribution of the pedagogical seminars to the seminar goals and the effectiveness of seminar activities

to the graduate students' learning. The needs assessment model (Borich, 1980) was used to evaluate the effectiveness of the seminar in helping graduate students to develop pedagogical thinking.

2. Not Too Ambitious? Graduate Student Teaching Practices in Studio

Christina Smith, Ann Sitomer, and Milo Koretsky

2.1 Introduction

Facilitating student learning in a small group environment is a complex teaching practice, one that takes preparation and skill to do effectively. Ambitious teaching is a construct that focuses on identifying, supporting, and improving teaching practices that are effective in student learning. Windschitl and Barton (2016) describe ambitious teaching as a "work in progress," which has been operationalized within K-12 science and mathematics education (Lampert, Boerst, & Graziani, 2011; Grossman, Hammerness, & McDonald, 2009; Ball & Forzani, 2009). We bring this construct into postsecondary engineering education work by focusing on teaching practices implemented by graduate students, who facilitate student learning in small group environments. In the context of innovative education reforms, graduate teaching assistants (GTAs) are asked to implement complex teaching practices that encompass aspects of ambitious teaching and are often not provided sufficient pedagogical development that would create a culture of ambitious teaching. GTAs need preparation to effectively facilitate student learning in the classroom. In order to provide effective preparation we need a better understanding of current GTA teaching practices in the classroom.

Educators within science, technology, engineering, and mathematics (STEM) focus on improving and enhancing student learning through the use of student centered, active learning strategies (Prince, 2004). These strategies leverage and build student learning through interactions with peers, instructors, and activities. One learning environment that aims at interactively engaging students in small groups are Studios within engineering (Koretsky, 2015). Within Studios, students are asked to

wrestle with core concepts in small groups, which are facilitated by a GTA. As students work together and explore the core concepts in Studio, GTAs interact with students and their emergent understanding of these core concepts. GTAs learn to do this work well by developing a set of teaching practices.

Windschitl and Barton (2016) suggest on focusing on a "core" set of teaching practices that can be refined by an instructor within a student-learning environment. For this study, we focus on the teaching practices of attending to group dynamics (Horn, 2011; Oakley, Felder, Brent, & Elhajj, 2004), promoting *interactive* engagement by eliciting student thinking to promote productive dialogue (Chi, 2009; Fonseca & Chi, 2011; Windschitl & Barton, 2016) and providing effective feedback (Gilbuena et al., 2015) within an engineering Studio. These teaching practices were identified as important within the Studio pedagogy and effective at promoting student learning.

This study is situated within a large research university engineering program in which GTAs are asked, as part of a program level design, to engage students interactively within a Studio environment. We ask the following research questions:

1. What is the nature of and how often do GTAs implement the teaching practices of attending to group dynamics, eliciting student thinking, and providing effective feedback in a junior level thermodynamics Studio?
2. What are student perceptions of these practices?

2.2 Background

2.2.1 Facilitating Student Learning

Within the engineering classroom, like in the science classroom, educators are implementing active learning strategies to improve the student experience and increase their learning gains (e.g. Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005; Perrenet, Bouhuijs, & Smits, 2000; Prince & Felder, 2007). Prince (2004) provides a description and analysis of the effectiveness of implementing active learning strategies in the classroom, which he defines broadly as "any instructional method that engages students in the learning process" (p. 1). Active learning is "student-centered" with activities that are often scaffolded, problem based, and designed to encourage interdependence among students through teamwork (Smith, Sheppard, Johnson, & Johnson, 2005).

In contrast to student-centered active learning, *passive* learning, is teacher-centered where students only take on an observational, listening role (Menekse, Stump, Krause, & Chi, 2013). There are discrepancies in studies on whether or not active learning is more effective than a traditional, or passive way of teaching. These discrepancies may be due to a lack of a shared language and frameworks, which do not bound the definitions of practice and therefore the effectiveness of those practices (Menekse et al., 2013). Chi (2009) addresses the lack of a framework by proposing the Differentiated Overt Learning Activities (DOLA) framework, which divides active learning methods into *interactive*, *constructive*, and *active*. Within her framework, she found that the *interactive* mode, is most effective at improving student learning, followed by the *constructive* and *active* mode, which in turn, are

more effective than *passive* (Chi, 2009; Menekse et al., 2013). In the *interactive* mode, students are cognitively active while engaging in socially collaborative discourse with one another and with the instructor.

Most of the research in active learning in engineering focuses on the choice and design of the activity itself and the gains in learning relative to the passive mode (Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005; Perrenet, Bouhuijs, & Smits, 2000; Prince & Felder, 2007). While this approach has provided valuable knowledge on effective types of activity, it backgrounds a key aspect of Chi's interactive mode, socially collaborative discourse. We are interested in ways to promote productive discourse between the instructor and students and the students themselves as they are engaged in activity. This shifts focus from development of activity to instructional practice. With this shifted emphasis, we borrow from the K12 math and science education communities' framework of *ambitious teaching* (Windschitl & Barton, 2016). Within this shift to teaching practice, however, we still acknowledge that activity design is critical to effective active learning environments.

According to Windschitl and Barton (2016), there are two assumptions that bind successful cases of teaching practices. The first is that ambitious teaching assumes that the quality of teaching is assessed by the engagement of all learners rather than just the completion of curriculum. The second assumption is that sustainable improvements in teaching require instructors (in our case GTAs) to have a "repertoire of practices" that influence student learning and are refined over time. The authors suggest the "core" repertoire of teaching practices should be few in number in

order to begin to develop instantiations of each and that these practices should be a part of a larger system of instruction that supports student learning.

In this study, GTAs are asked to prompt students to engage *interactively* to develop their conceptual understanding and procedural fluency. There are several teaching practices that support Chi's elements of social collaboration and cognitive activity. A GTA who is asked to facilitate an *interactive* learning environment needs to be able to recognize and attend to group dynamics in order to promote productive group interactions.

Within the role of facilitators, GTAs have the ability to create norms within groups by the way that they interact with them. Horn (2011) suggests that a facilitator should focus on social dynamics and status within groups by noticing student participation, body language, and by modeling good listening practices in order to create an equitable learning environment. Oakley et al. (2004) discuss that in order to turn groups into effective teams, an instructor can set guidelines and expectations regardless of whether or not the teams are assigned or self formed. While Oakley et al. (2004) focuses on instructors who are designing the course, GTAs have the power to set norms and expectations for groups through how they facilitate interactions between students. This can be done by attending to status, helping students create an environment of trust, and instill a sense of confidence in each group member (Shimazoe & Aldrich, 2010; Finelli, Inger, & Mesa, 2011; Johnson, Johnson, & Smith, 2007).

To promote cognitive activity, the GTA facilitator can prompt students to explain answers or their thought process aloud. Eliciting student thinking gives the

student the opportunity to organize her/his thoughts and provides opportunities for other students to engage in productive dialogue through interactions (Chi, 2009). The activity students are asked to engage with may prompt them to individually explain concepts or principles. Self-explanations are beneficial for students because they allow them to become aware of their current understanding, identify areas of confusion, and provide them the opportunity to update existing mental models (Villalta-Cerdas & Sandi-Urena, 2013; Chi et al, 1994). However, Chi identifies self-explanations as a *constructive* activity, which is not as effective as *interactive* activities. Fonseca and Chi (2011) provide a summary of studies that provide evidence that interactive tasks compared to self-explaining tasks result in larger learning gains. Promoting students to verbalize and explain for their own understanding may help other students in a group identify and recognize multiple ways to think about a problem or concept, creating an *interactive* environment (Chi, 2009). It also allows for a facilitator to understand the current thinking of a student and the types of "resources" that s/he brings into the classroom environment. These "resources" can be concrete, such as prior experiences or intuitions, as well as epistemic, such as how a student believes knowledge is constructed (Maskiewicz & Winters, 2012; Hammer & Elby, 2002).

Windschitl and Barton (2016) provide an example of ways a facilitator can elicit student thinking to shape instruction. Within this example, the goal for the practice of eliciting student thinking is to "reveal, on the social plane of the classroom, a range of resources (conceptual, experiential, epistemic, cultural, and artistic) that students use to initially gain access to a set of science ideas to activate prior knowledge, and to use

this information to shape further instruction" (p. 1131). To achieve this goal, the authors suggest the following practices:

1. Eliciting students' ideas
    a. Initiating a conversation
    b. Transitioning to hypothesizing
    c. Focusing on explanatory talk
2. Selecting ideas to make public
3. Adapting further instruction

These suggestions provided by Windschitl and Barton (2016) for eliciting student thinking indicate the layered and progressive nature of teaching practices.

Finally, providing effective feedback to students is an important practice to facilitate student learning. Gilbuena et al. (2015) synthesize literature on feedback and identify two forms of feedback: affirmative or corrective. Affirmative feedback acknowledges a correct response, but does not have the goal to prompt change whereas corrective feedback does (Diefes-Dux, Zawojewski, Hjalmarson, & Cardella, 2012; Gilbuena et al., 2015). Corrective feedback has two functions: directive feedback, which indicates to a student what needs to be corrected, and facilitative feedback, which guides the student to their own revision (Black & William, 1998). In the context of this study, we focus on the corrective feedback GTAs provide to students either while responding to a student question or proactively engaging a student or group. Hmelo-Silver and Barrows (2006) identify strategies of "expert facilitators," which included facilitative feedback in the form of scaffolded questioning, promoting group discussions through questioning, and modeling

questioning strategies for students. These strategies indicate the importance of questioning in promoting a facilitated discussion among a student and GTA or a student with other group members (King, 1992). The practices of attending to group dynamics, eliciting student thinking, and providing effective feedback, are progressive in nature and require time, practice, and skill to implement. They are also practices that are promoted within the Studio pedagogy, which is described next.

2.2.2 Studios

The implementation of Studios was part of a program-level course redesign aimed at increasing the frequency of interactive learning in the classroom (Koretsky, 2015). Within ten core Studio courses, a faculty member will instruct 150-250 students in a large-class setting. These students are then divided into multiple Studio sections of approximately 24 students; GTAs facilitate learning in Studios. This course structure is designed to present students with new information at the beginning of the week followed by opportunities to interactively engage with the concepts and with their peers during the week.

A GTA leads each of the Studio sections in the role of a facilitator. In this role, they interact with students as they work in groups by attending to interpersonal dynamics, noticing their thinking, and asking guiding questions. Koretsky (2015) writes that the objectives for the Studios are to:

1. Provide an environment where a large number of students are interactively engaged.
2. Design a learning environment that allows strategic implementation of *interactive* learning pedagogies, which allow relatively easy scaling.

3. Provide a scaffolded support structure for GTAs which:
    a. Help them develop teaching skills
    b. Increase the value they place in teaching
    c. Increase knowledge of how students learn

Figure 2.1 shows the structure of the thermodynamics Studio course in this study. The course met in the large-class format with 199 students three times a week (Monday, Wednesday, and Friday) and in Studio with approximately 30 students on Thursday. In the Wednesday large-class meeting, the Concept Warehouse, a technology-based interactive tool, was used to engage students in conceptual learning (Koretsky et al., 2014). Student groups in Studio were created using the Comprehensive Assessment of Team-Member Effectiveness (CATME) Team-Maker (Ohland et al., 2006).

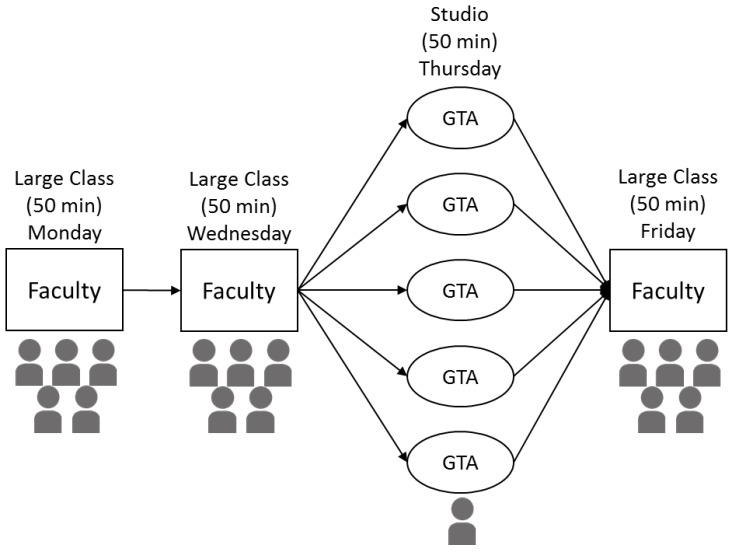

Figure 2.1. Structural design of thermodynamic course

For this study, we focus on specific GTA instructional practices in Studio, including attending to group dynamics, eliciting student thinking, and providing

facilitative and directive feedback to students, all practices that are promoted within the Studio pedagogy (Koretsky et al., 2012; Koretsky, 2015). Each practice requires a particular set of skills in order to implement them effectively. A GTA needs to be able to monitor student conversations and look at student work to determine whether or not to intervene to promote a more productive dialogue. A GTA would need to be able to have enough content knowledge and pedagogical content knowledge (Hill, Ball, & Schilling, 2008; Ball, Thames, & Phelps, 2008) to know how to elicit student thinking and what type of feedback would promote a more productive dialogue. With this analysis, we seek to "benchmark" GTA teaching practices so that we can better strengthen and expand their repertoires.

In order to achieve visions for undergraduate education that rely on more complex teaching practices, we need to be able to more systematically support ambitious teaching practices. In terms of ambitious teaching in the Studio environment, GTAs are not designing activity but rather enacting practices within a program redesign. The practices of focus in this study are challenging given the constraints of the learning environment, e.g. number of students/groups, size of the room and ability to navigate the space, and time. Other challenges for GTAs come in the form of content and pedagogical preparation, expectations from the instructor and from students, and preparation time. Many of these constraints are out of the control of the GTA, however pedagogical preparation may be made available through the department and is key to help GTAs more effectively navigate these complex practices and make more informed decisions (Barnhart & van Es, 2015).

2.3 Methods

This study is a qualitative studying investigating GTA teaching practices through observational data and open-ended student written response data. This study is part of a larger study that includes interviews and stimulated recall interview (SRI) data focused on the epistemology of the GTAs.

Data sources for this study included:

- Video recordings of the two GTAs in practice. Each GTA was recorded during two different Studio activities
- A student survey evaluating the effectiveness of and access to the two GTAs

2.3.1 Setting

The GTAs in this study were asked to facilitate learning within the second term of a junior level thermodynamics course at a large research university. The thermodynamics course is part of the Studio program-level course redesign, and had a class structure that valued conceptual understanding and interactive engagement of students within the classroom. The data were gathered in two meetings of Studio in the thermodynamics course. The first Studio focused on the thermodynamics of mixtures. The activities included the following: a pre-experimental activity that focused on students setting up the experiment and making predictions; an experimental activity, which asked students to perform a simple experiment and make observations; and a discussion activity that asked students to discuss the major findings and connect observed values to the theoretical nomenclature.

The second Studio focused on the fugacity of mixtures. Students were given a series of scaffolded questions that stepped them through the process of developing an

expression of fugacity from an equation of state for a binary mixture. Students needed to understand mathematical concepts such as double summation, partial derivatives, and integrals and reason through and apply assumptions to the system. This Studio was closed note, book, and calculator and required each group to turn in one solution. This instructional choice was made so that students would need to focus on executing the mathematical steps themselves rather than searching for an example elsewhere. To motivate productivity, students were told that the group that got the furthest and had the most accurate solution would get a small amount of extra credit Studio points.

2.3.2 Participants

Two GTAs were selected for the study. The first GTA, Dean (pseudonym), was in his third year as a chemical engineering doctoral student. As such, he had experience being a GTA in several Studio courses including this thermodynamics course, which he facilitated during his first year as a graduate student. Dean had also worked as a GTA in a junior-level heat transfer course, and senior-level design and unit operations courses. In the thermodynamics course in this study, Dean facilitated three Studio sections, two of which were recorded. Dean received his B.S. in chemical engineering from a large research university in the Southern US, where he had previous experience as an undergraduate teaching assistant and as a mentor for high school science students.

The second GTA, Jeff (pseudonym), was in his first year of a chemical engineering doctoral program. Jeff had one term of GTA experience in a sophomore-level material and energy balances Studio course. During this study, Jeff facilitated two Studio sections one of which was video recorded. Jeff had three years of

experience as a chemistry tutor at his undergraduate university, a different large research university in the Southern US. His role as a tutor included answering questions for students in a designated space, as well as one-on-one tutoring sessions.

Dean and Jeff both attended weekly meetings with the instructor of the thermodynamics course, an experienced educator and advocate of active learning, to discuss issues in the previous Studio, the GTAs' teaching practices, go through the upcoming Studio assignment, and work through potential difficulties and misconceptions that students might have. These meetings also included conversations around exams and other administrative issues. During the Studios, the GTAs were asked to facilitate student learning by asking guiding questions based on the objectives of the particular Studio activities. The instructor of the course would regularly visit each Studio briefly to assess if the learning environment was consistent with the instructional and pedagogical goals. The GTAs also attended a GTA pedagogy seminar, which was a designated space for GTAs from all Studio courses to come together and discuss their practice and concerns. The thermodynamics instructor the GTAs were working with facilitated this seminar.

2.3.3 Data Sources

Both GTAs were video recorded facilitating the same Studio activities. The layout of the Studio room varied from long tables with movable chairs to movable sitting desks. A microphone was placed on the GTA that transmitted to a single camera at the front of the room. The first author started the recordings at the beginning of class and then left in order to not disrupt the Studio. Both the video

recordings and student evaluations were used to identify the teaching practices that each GTA enacted.

Student evaluations of the GTAs in the Studio were collected during the seventh week of the ten-week term. Students were asked to assess the GTAs by the following prompts:

- The TA/instructor is a good resource for me to complete the Studio Worksheets (Likert scale, strongly disagree (1) to strongly agree (5))
- The TA/instructor is able to spend enough time with me during the Studio to help with my questions on the Worksheets (Likert scale, strongly disagree (1) to strongly agree (5))
- Write down one thing the TA/instructor is doing well (written response)
- Write down one thing that the TA/instructor could improve in Studio (written response)

2.3.4 Data Analysis

Video recordings were reviewed and utterances coded by the first author. Codes are shown in Table 2.1 and include several ways for Facilitative Feedback and a code for Directive Feedback. The sub-codes in the Facilitative Feedback category are based on the practices of interest: attending to group dynamics, eliciting student thinking, and providing feedback. Providing feedback was broken up into facilitative, reactive and proactive, and directive feedback. The unit of analysis was an utterance, which was defined as a complete sentence, thought, or question that the GTA uttered. In regards to a direct response, each time the GTA provided new information during an explanation or affirmation, it was counted as an occurrence. Any utterance not

related to the Studio, such as a joke, discussion around grades, or a general class announcement, was not counted. Counts were averaged between two Studio sections for Dean and rounded up to the nearest whole number. A total of 100 minutes were coded for Dean for each of the two Studios (for an average of 50 minutes) and 50 minutes for Jeff.

Another researcher on the project coded a randomly selected percent of the video recordings: (5 minutes) of each studio and each GTA (four videos total) were coded to establish inter-rater reliability. These two researchers independently coded for specific occurrences of each code identified in Table 2.1 through an iterative process. This coding resulted in acceptable interrater reliability with a Cohen's Kappa of 0.70.

Table 2.1. Description of teaching practice components

	Observation	Description	Example
Facilitative Feedback	Attending to group dynamics	GTA addresses members of the group, asks them to interact with one another	"I'm going to walk away, talk amongst yourselves"
	Eliciting student thinking	GTA acknowledges student thinking or line of thinking, may ask questions around it or build on the explanation	"I like that line of thinking, what do you think about this?" "Tell me why."
	Reactively providing feedback with facilitating questions	GTA responds to a student question by using questions, each facilitating question related to the original student question is counted here	"What is the density of water? What is the density of ethanol?"
	Proactively giving feedback through facilitating questions	GTA moves student thinking along by proactively asking questions, each distinct question is counted	"What would you do first?"
Directive Feedback	Other direct feedback	GTA does not answer a question with a question, but explains a concept or idea to a student or group, gives affirming responses, or gives a direct answer	"Okay." "Correct." "The density of water is…"

Student written responses were coded thematically (Riessman, 2008), with the goals of Studio and the facilitation of the GTA guiding the interpretation. Table 2.2 gives a description of the codes that emerged for what the GTA was doing well, which included: reaches all groups, facilitation of student learning, direct guidance, and interpersonal attributes.

Table 2.2. Description of codes for what the GTA was doing well in Studio

Theme	Feature of Practice	Definition	Example
Reaches all groups	Attending to group dynamics	Student observes or comments that the GTA circulates to all groups	"He is pretty good with helping every group, not just spending the whole time with just one specific group"
Facilitation of student learning	Eliciting student thinking Feedback provided to students	Student indicates the GTA helped them think critically, problem solve, or facilitated their learning without giving answers	"Giving us hints and tools we need to do the problem without giving the solution" "Giving us enough space to form our own ideas on problem solving methods"
Direct guidance		Student states that the GTA clarifies or explains a concept, problem, the studio worksheet, etc.	"Explaining things at the beginning of class well" "He explains answers well"
Interpersonal attributes		Student describes attributes of GTA	"He is approachable" "TA is explaining questions more patiently and more detail"
Other		Topics included: autonomy, setting norms, timely grading, organized and prepared, or no response	

Table 2.3 gives a description of codes that emerged for what the GTA could improve include: reach all groups, direct guidance, class wide lecture or discussion, and preparation. These were then categorized into the three practices of interest.

Table 2.3. Description of codes for how the GTA could improve in Studio

Theme	Feature of Practice	Definition	Example
Reach all groups	Attending to group dynamics	Student states that the GTA could improve on reaching all of the groups including answering more quickly	"Answer the question that are asked by the groups a little faster"
Direct Guidance	Eliciting student thinking Feedback provided to students	The student states the GTA could improve in how he answers questions, explains concepts, gives hints, etc.	"More guidance would be helpful. For example, last term in thermo TAs would write relevant equations and tips on the board. [sic]" "Explain concepts related to the studios and how exam questions we might face (sic)"
Class wide lecture or discussion		Student suggest the GTA address the whole class when students are struggling or to provide general information	"At the end of studio it would be helpful to review what the end goal was and walkthrough if there was any misconceptions still afloat"
Preparation		Student states the GTA needs to be prepared for the Studio, which may include having access to and looking at solutions or is comfortable with the material	"Giving background to the problem and actually knowing how to do the studio correctly" "The TA could know the solution to the studios ahead of time so that he knows if we are completing them correctly"
Other		Topics included: autonomy, doing fine, grades, office hours, studio components	

2.4 Results and Discussion

2.4.1 Research Question One: Nature and Occurrences of Teaching Practices

2.4.1.1 Nature of Teaching Practices

Studio 1: Mixing Experiment

The Mixing Experiment Studio was conceptually oriented and lab-based meaning students were asked to work with physical equipment and connect experimental design and experimental observations to foundational concepts. Within Studio 1, questions from students centered around the concepts of density, temperature and volume change, partial molar volume of water, and nomenclature.

Dean

Dean handed out homework at the beginning of class and gave a brief introduction to the Studio. While handing out papers, there are limited questions, perhaps because Dean has set a norm that he won't answer questions, or the students are taking time to read over the studio and think about what they need to accomplish. For this particular studio, students are asked to run an experiment with water and ethanol. Dean asks each group to explain their reasoning before getting experimental materials and moving forward. During his first Studio section, he spends more time with groups and their explanations and getting them to think about density and other concepts. While doing this, he tries to use analogies with familiar substances, e.g. oil and vinegar, with mixed success. On occasion he summarizes student ideas. In his second Studio section, he listens to student explanations and often does not prod the students further.

Dean would often respond to student questions with an explanation rather than asking them questions. Within some of these explanations, he'll offer how he thinks about problems or the important aspect of the question. He continually walks around the room and observes and interacts regularly with all the groups. Often he'll talk to a whole group, but does not explicitly tell them to turn to one another and discuss. When students explain, typically only one student explains and Dean does not prompt other students to engage.

Jeff

Jeff has students pick up homework before class starts; once he begins Studio students are asked to wait to pick up homework. He starts off the Studio with a brief

explanation of the Studio and talks about issues he saw in the homework. Once the students start, Jeff circles the outside perimeter of the room. It seems as though it is difficult to get to the students in the middle of the aisles due to the room set-up, however when the instructor comes in he walks down the middle and interacts with the groups that Jeff did not reach. As Jeff interacts with students, he stresses the importance of units and notation and his explanations are procedural in nature. Throughout the Studio, Jeff collects the experimental materials from each group, which appears to distract him from engaging with students more fully. One observable difference between Jeff and Dean's facilitation is that Dean made the decision to not let students start with the experiment until they explained to him their reasoning for their experimental procedure, following the design of the Studio. This decision led to Dean interacting with students more.

Studio 2: Fugacity of Mixtures

The Fugacity of Mixtures Studio was procedurally oriented and required students to engage deeply with mathematical concepts in developing an expression for the fugacity a binary gas mixture. In Studio 2 students primarily asked "check-in" questions such as "does this look right?" as well as mathematics operational questions (e.g. double summation, quotient rule).

Dean

At the start of Dean's first Studio section, he again passes papers back and then begins announcements. He begins to go over a midterm make-up question with the whole section. While doing so, he asks for students to shout out the answers and participate. Concluding this mini "lecture," he explains that the Studio focuses on

their ability to do math and that he is "allowed" to help them this time. His responses to student questions are more directive than facilitative, telling them procedurally how to do mathematical operations. At the start of his second Studio section, Dean also explains parts of the midterm with which the students struggled; however he receives push back from some students in regards to the implementation of the midterm make-up. Dean does not explicitly tell his first Studio section that Studio 2 is a competition, although it is written on the Studio worksheet. He does state it is a competition in his second Studio section. Dean passes back homework, which may hinder his engagement with students.

There is a visual difference between Studios 1 and 2. In Studio 1 students each had their own worksheet, for Studio 2 each group had one worksheet within each group. Students are looking at each other, pointing to the paper, and typically more than one student can be heard participating in a group. In both Studios, Dean proactively works from group to group to check in. For Studio 2 most student questions center on mathematical concepts and students checking in with their work. However in Dean's second Studio 2 section, a student asks "what is fugacity?" There is then an exchange between Dean and the student where Dean outlines how he thinks about fugacity. In his first Studio section, students stay over time with questions indicating that several groups did not finish.

Jeff

Jeff starts this Studio with announcements and discusses the studio and how math heavy it is, framing it as "tedious" math. Similar to Dean, student questions are checking in to see if they're doing the mathematics correctly. Jeff explains

procedurally but takes a step back to observe and look at student work. He gives students hints to help them before they get to the math, for example telling them or asking them about mole fraction and what that means. Jeff hands papers back while walking around, which might distract him from engaging with groups proactively.

2.4.1.2 Occurrences of Teaching Practices

Video recordings of Dean and Jeff were analyzed focusing on practices of facilitating student learning (see Table 2.1 codes for video observation). In a 50-minute Studio, there were between 124-171 feedback interactions with students. Table 2.4 indicates the percentage of interactions that were facilitative and the percentage that were directive for each TA in each Studio. In all cases directive feedback was more common. Table 2.5 delineates the number of occurrences of the particular practice of Facilitative Feedback.

Table 2.4. Percentage of facilitative and directive feedback

	Dean		Jeff	
	Studio 1 (n = 171)	Studio 2 (n = 148)	Studio 1 (n = 124)	Studio 2 (n = 152)
Facilitative Feedback	30%	16%	13%	24%
Directive Feedback	70%	84%	87%	76%

Table 2.5. Number of occurrences of facilitative practices

	Feature of Practice Observation	Dean (# of occurrences)		Jeff (# of occurrences)	
		Studio 1	Studio 2	Studio 1	Studio 2
Facilitative Feedback	Attending to group dynamics	3	1	2	6
	Eliciting student thinking	12	5	2	3
	Reactively providing feedback with facilitating questions	17	2	1	3
	Proactively giving feedback through facilitating questions	20	16	11	24

Both Dean and Jeff had numerous interactions during Studio; however, they were usually directive. They both rarely attended to group dynamics by asking students to interact with their group. They both spent time providing direct explanations to questions and asking questions to move student thinking along. Both GTAs elicited student thinking and provided facilitative feedback, but Dean was much more likely to implement both practices.

Differences in table counts could be due to the following:

- Difference in Dean could be that he feels "allowed" to help them in Studio 2
- Difference in Jeff could be Studio 2 aligns with his procedural "nature" (He gives students hints to help them before they get to the math)

The first Studio was lab-based; students were asked to work with physical equipment. The second required students to engage deeply with mathematical concepts in creating an expression for a binary gas mixture. Within Studio 1, questions from students centered around the concept of density, temperature and volume change, partial molar volume of water, and nomenclature. In Studio 2 students primarily asked "check-in" questions such as "does this look right?" as well as mathematics operational questions (e.g. double summation, quotient rule).

2.4.1.3 Examples of Teaching Practices

Below are examples of Dean and Jeff's response to students during Studio 1, which focuses on the mixing of ethanol and water. The episodes illustrate the findings reported in Table 2.4 and were chosen because they occurred at a similar time, nine minutes into the Studio as students were completing the pre-experiment activity.

Studio 1 Example of Dean Teaching Practice

Dean is reacting to a student question.

S1: Should we assume perfect mixing for this?
D: I think that that's something you guys have to decide on. But that's a good question though. (*reactive directive feedback*)
S2: Well I was thinking that you'd probably want to put the water in first cause it has like smaller molecular mass, so more water molecules…
D: Okay. (*directive feedback*)
S2: …and then ethanol is going to be bigger, so there's less ethanol molecules in 40 mL. So there'd be more effective mixing if you have, pour the water in first.
D: I think your line of thinking is good, think about what might be more important than the mass of the molecule. (*eliciting student thinking, directive feedback*)
S2: Like the hydrogen bonds or something?
D: So, go away from chemical and think more physical. But you're on the right track. (*directive feedback*)
[walks away]

Within this episode, Dean directly responds to a student 1's question. He gives student 2 space to think aloud, acknowledges student 2's current thinking, and provides student 2 with directive feedback to take the next step before walking away.

Studio 1 Example of Jeff Teaching Practice

Jeff stops and listens to a group of students discussing the Studio worksheet and proactively asks a question.

S1: The ethanol should be poured into the water right?
S2: Yeah.
J: Why do you think that? (*eliciting student thinking*)
S1: Because…
S2: Because if you do it the other way, it's gonna blow up.
S1: Yeah, well it'll, no…
J: Blow up?
S1: Not blow up, but it'll start reacting, like right when the, I feel like if you pour the ethanol into the water it'll start reacting right as you, er add the water into ethanol, right as you start pouring, but…I'm not exactly sure but I think that the reaction will be…

J: Well there's not going to be a reaction right? Cause water and ethanol don't like, react. (*directive feedback*)
S1: Well not react but like, like the molecules will like, I mean I don't know [laughs] I don't know how to describe it honestly.
J: So if you were like trying to, let's say you were trying to mix something right? (*directive feedback*)
S1: Uh huh.
J: What would you pour first? The stuff that would sit on top or the stuff that would sit on the bottom? (*proactively giving facilitative feedback*)
S3: Oh, so we consider the density of water.
J: Right, yeah. (*directive feedback*)
S3: Which one is bigger? Is larger?
S1: Doesn't ethanol have a smaller density than water?
J: Yeah, ethanol's lighter right? It's like point… (*directive feedback*)
S2: So is that more or less than water?
S1 + J: Ethanol's less dense.
S2: So wouldn't you…
S1: …I guess you'd pour the water into the ethanol then.
J: Right. (*directive feedback*)
S2: So it mixes while the ethanol is there.
S1: Yeah… [pause] but isn't there like a reaction, it produces a certain amount of heat doesn't it?
J: But it's not a reaction, it just mixes right? (*directive feedback*)
S1: Yeah.
J: If it was a reaction then something would chemically be changing. (*directive feedback*)
S1: Yeah. But I don't know what you'd call that?
J: It's mixing. (*directive feedback*)
S1: It's just mixing? Yeah.
J: Cause you can separate it completely. (*directive feedback*)

Within this episode, Jeff engages with a group of students by asking them what they think. He also gives the students space to talk concepts out and corrects their thinking directly. Jeff then asks a general, facilitating question about which substance the students would pour first. At this point a third member chimes in and the conversation continues. Student 1 is struggling with the concepts of mixing and reactions, which Jeff addresses directly rather than engaging in a conversation. Jeff also does not prompt other members in the group to respond to questions or confusions.

2.4.1.4 Summary

Observations of practice and Table 2.4 indicate that both GTAs interact with students heavily through direct guidance (70-87%). This is in part due to both GTAs choosing to procedurally provide information to students rather than asking guiding questions. Looking at occurrences, Dean engages with students slightly more often in a facilitative manner when compared to Jeff. This may be due to his epistemology and experience within the Studio learning environment or the nature of the two Studios. Within the examples provided, Dean acknowledges student thinking and begins to ask a facilitating question. Jeff also asks a facilitating question. Neither attends to group dynamics. Dean, to some level within Studio 1 engaged with each level of ambitiously eliciting student thinking. He elicited student ideas by asking them what they thought; selected ideas to summarize, or make public, when talking with groups, and adapted his further instruction by realizing what worked and what did not work. One example of Dean adapting his practice is by using an analogy of oil and vinegar with one group and trying the same analogy with another group. The second group was confused by the analogy and Dean did not use the analogy after that point in either section for Studio 1. Jeff did not summarize student ideas and it is unclear if he adapted his practice based on student responses to his questions.

Ideally, there would be a more even occurrence of each facilitative practice used throughout the Studio by both GTAs. Observations indicate that there is not enough development in the practices that Studio pedagogy focuses on, which are attending to group dynamics, eliciting student thinking, and proactively providing facilitative feedback.

2.4.2 Research Question Two: Student Perceptions of GTA Practice

Students in Studio were given a survey evaluating the GTA three weeks before the end of the ten week term. Student responses indicated what their expectations were and a glimpse into what they believed the GTA's role was. The students were asked two Likert scale questions about the GTA as a resource and his ability to spend time with the student, which are shown in Table 2.6. Overall, students felt as though the GTAs were a good resource and able to spend enough time with them during Studio.

Table 2.6. Student Likert responses of the GTAs

Likert Question	GTA	Mean	Strongly disagree (1) – Strongly agree (5)		
			Disagree (1, 2)	Neutral (3)	Agree (4, 5)
The TA/instructor is a good resource for me to complete the Studio Worksheets	Dean (n=54)	3.74	11%	24%	65%
	Jeff (n=35)	3.31	31%	14%	54%
The TA/Instructor is able to spend enough time with me during the Studio to help with my questions on the Worksheet	Dean (n=54)	3.43	17%	35%	48%
	Jeff (n=35)	3.29	20%	34%	46%

Students were also asked to respond to two open ended statements: "write down one thing the TA/instructor is doing well" and "write down one thing the TA/instructor could improve in studio." Table 2.7 shows the themes and number of responses. Themes that emerged for what the TA was doing well included the ability of the GTA to reach all groups, facilitating student learning without giving answers, clarifying and explaining, as well as interpersonal attributes of the GTA. Reponses also included the autonomy of the GTA, how the GTA set norms, timely grading, whether the GTA was organized and prepared, or no response. There were four or

less responses for each of these themes, and therefore were combined into an *Other* category.

Table 2.7. Percentage of themes of what the GTA is doing well in Studio

Theme	Feature of Practice	Dean (n=53)	Jeff (n=35)
Reaches all groups	Attending to group dynamics	11%	11%
Facilitation of student learning	Eliciting student thinking	49%	37%
Direct guidance	Feedback provided to student	25%	20%
Interpersonal attributes		21%	20%
Other		21%	31%

The majority of the responses fell within the *Facilitating of Student Learning*. Student responses provide their perspective on how the GTA elicits their thinking and the type of feedback they are provided. Overall, the students suggested that the GTAs are effective at guiding their thinking and giving the authority of knowledge production to them. In contrast there were a large number of responses that stated GTA practices were more directive, indicating that students value direct answers from the GTA. This puts students in more of a passive role. In regards to attending to group dynamics, reaching all students is the bare minimum and students focused on whether or not the GTA made it to all of the groups rather than how he facilitated group dynamics.

In regards to what the TA could improve to enact the practices that are important in the Studio learning environment, themes emerged around facilitation practices including: reach all groups, direct guidance, class wide lecture or discussion, and preparation. Again, disparate responses of five or less were combined into 'Other' shown in Table 2.8.

Table 2.8. Percentage of themes of how the GTA could improve in Studio

Theme	Feature of Practice	Dean (n=53)	Jeff (n=34)
Reach all groups	Attending to group dynamics	13%	6%
Direct Guidance	Eliciting student thinking	53%	59%
Class wide lecture or discussion	Feedback provided to students	11%	15%
Preparation		15%	15%
Other		34%	41%

2.4.2.1 Summary

When asked what the GTA could improve on, most students wanted more direct guidance, either in the form of explanations or lectures. The expressed desire for improvement in these practices indicates that the GTA is either not doing them or not doing them effectively. As was discussed in the previous research question regarding observed practices, the GTAs spend a large amount of time explaining rather than questioning, which contradicts the student perception of practice.

From the student epistemological perspective, the indication that students want more direct guidance suggests they do not understand the purpose or goals of Studio or the role of the GTA. Dean noted this by saying the following after looking at the same data during the course:

> "… we did get our reviews…and a lot of people were still saying 'oh the studios are too long, we can't finish them, the instructor's not giving us enough help to finish them,' all those kind of typical complaints you'd expect to hear from people who've never done studio before, and so last week I went back and I had to reiterate why, exactly, what the purpose of studio was…as of Thursday of last week if they don't understand then they just aren't listening to me, at that point they're doomed anyway."

Dean did acknowledge that some students "understood the point of studio" but that "50-75% still think about studio as the need to get it done in the 50 minutes to get the 10 points…" In Dean's case, he indicated that he reflects on the student comments on his practice. While reflecting on practice is beneficial, in this case student perceptions of practice do not completely align with the goals of the pedagogy in Studio. Within the student responses, students provided suggestions, which included starting the Studio with an overall explanation of the Studio and concluding with a class overview of important concepts. Students want the GTA to address the entire class in a lecture like format when multiple groups are struggling. This removes the authority of learning from the students and their peers back to the GTA who is perceived as the authority, which is contrary to the goals of Studio.

2.5 Conclusions

Graduate teaching assistants (GTAs) are asked to implement complex teaching practices and are currently not provided sufficient pedagogical development that would create a culture of ambitious teaching (Windschitl & Barton, 2016). Windschitl and Barton (2016) suggest identifying a set of core teaching practices to develop in facilitators as part of a larger system that focuses on student learning. GTAs within a large research university engineering program are asked as part of a program level design to engage students interactively within a Studio learning environment. The teaching practices that were identified for this study as important core practices within the Studio learning environment and effective at facilitating student learning, were attending to group dynamics, eliciting student thinking, and providing effective feedback.

GTAs within a junior level thermodynamics Studio showed primarily directive rather than facilitative feedback throughout two Studio sessions. Some students wanted more directive feedback and some students appreciated the facilitative feedback. These two results indicate that there are tensions between the design and implementation of Studio teaching practices as well as between the implementation and reception by students of those teaching practices. Studios are designed to have students *interactively* engaging with each other in small groups. GTAs in a facilitating Studio role are asked to notice and foster groups dynamics, promote productive dialogue to have students interactively engage with each other and the material, (Chi, 2009; Fonseca & Chi, 2011; Windschitl & Barton, 2016) and provide facilitative feedback. However the majority of interactions the GTAs in this study had with students were directive and they rarely facilitated students to interact with other group members. It would be beneficial within the weekly instructor meetings or within another informal environment, to discuss and practice focusing on fostering productive group dynamics within Studio. The tension between GTA implementation and student reception of facilitative practices partly stems for students not being comfortable with Studio pedagogy.

There are several limitations to this study. The first is that GTAs were encouraged to implement the three core Studio teaching practices within group meetings with the instructor as well as voluntary meetings with other Studio GTAs. However, focusing on teaching practices was not an explicit goal of the instructor meetings. Also the student survey data question “The TA/instructor is able to spend enough time with me during the Studio to help with my questions on the Worksheets”

focuses on the individual's learning in an environment that supported collaborative learning. Finally, we recognize that observations and student data do not provide a complete picture as to why GTAs make decisions in the classroom. To understand the impetus behind what we observed, we need to understand the in-the-moment decisions being made and the epistemological perspective GTAs bring into the classroom (Speer, 2005; 2008). Speer (2005; 2008) suggests one way to understand practice and epistemology is through reflective, stimulated recall interviews (SRIs). Incorporating SRIs and interview data would be the next step of study to understanding GTA teaching practices within Studio learning environments.

2.6 Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. DUE 1347817. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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3. Graduate Teaching Assistant Enacted, Professed, and Reflected Epistemological Resources and Frames within a Studio Environment

Christina Smith and Milo Koretsky

3.1 Introduction

Currently engineering graduate students at large research universities are provided limited opportunities to engage in pedagogical development before entering the classroom as Graduate Teaching Assistants (GTAs). This is problematic because they are not adequately prepared to engage in the complex work of facilitating student learning. Specific aspects of facilitating student learning, or student centered learning, that are accessible to novice instructors include attending to group dynamics, eliciting student thinking, and providing feedback to students (either directive or facilitative). In order to improve practice, and student learning, and eventually to provide GTAs with pedagogical development opportunities, we need an in-depth understanding of how GTAs are making pedagogical decisions including their epistemological perspective.

Epistemology, what one believes counts as knowledge, its production, and learning, has a direct connection to practice. How a GTA perceives knowledge and learning will influence the decisions s/he makes within the classroom through how s/he chooses to interact with students and the environment. There have been several models or areas of study of epistemology. Models include a developmental epistemological trajectory (Perry, 1970; Magolda, 1992; Belenky et al., 1986), how epistemology influences reflective and reasoning processes (King & Kitchener, 1994; Kuhn, 1991), and epistemology as a belief system (Schommer, 1990; Schommer-Aikins, 2002, 2004; Hofer & Pintrich, 1997). In a response to the unitary ontology of these frameworks, Hammer and Elby (2002) present a manifold framework that allows for a more nuanced approach in understanding epistemology by

acknowledging that context is influential in the activation of epistemology. They introduce the concept of *resources* as fine-grained elements of an epistemology that can be activated within different contexts. The contextual nature of this framework allows us to take into consideration the differences within any given learning environment that an instructor negotiates and acts upon.

These models come from the work of educational psychology and education and have been extended to STEM contexts, primarily in mathematics and physics. Within the realm of engineering, research on epistemology has primarily focused on students, using questionnaires as the source of data (Yu & Strobel, 2011, 2012; Carberry, Ohland, & Swan, 2010). The limitation of questionnaires is that they do not allow for the complexity of epistemology and the relation to the learning environment to be taken into consideration. On the other side of the spectrum, Montfort, Brown, & Shinew (2014) investigate the epistemology of civil engineering faculty members in an effort to contribute to the development of a theoretical framework. The authors acknowledge that faculty epistemology will influence and are influenced by views of motivation, models of learning, and familiarity with learning theories (and in this case facilitating student learning). These studies and calls for understanding epistemology in engineering (Douglas, Koro-Ljungberg, and Borrego, 2010; The Steering Committee of National Engineering Education Research Colloquies, 2006) acknowledge that epistemology is an important factor to understanding the learning environment but focus on the student and faculty perspective. Engineering graduate students have been neglected in this research but they are also active participants in the learning environment as facilitators of student learning, typically in recitations,

labs, or Studios. Therefore, we need to better understand how to help them become effective facilitators in the classroom.

Previous studies connecting epistemology and practice (Speer, 2005; Haney, Lumpe, Czerniak, & Egan, 2002; Schoenfeld, 1998) focus on consistency between a "professed," or stated, epistemology and an "enacted," or observationally inferred, epistemology (Louca, Elby, Hammer, & Kagey, 2004). Typical data sources for a professed epistemology are interviews or questionnaires while enacted epistemology is inferred from observations or self-reports (Speer, 2005). Speer (2005) argues that this approach to understanding practice and epistemology is methodologically flawed and that researchers can more purely understand the in-the-moment decisions of instructors by studying the practice and epistemology in tandem through reflective interviews. If we are able to more directly understand the relationship between practice and epistemology and the in-the-moment decisions that GTAs are making in the classroom, we can develop more effective pedagogical development that will aid them in improving their practice.

For this study I adopt Speer's methodology and extend her work by bringing it into an engineering context. I build on previous work (Smith, Sitomer, and Koretsky, 2017) that focused on the practices of GTAs asked to implement a reformed based pedagogical practice in a thermodynamics course. In this study I continue a case study of two GTAs within this course and examine their professed and reflected epistemologies through pre-, post-, and stimulated recall interviews. I ask a series of questions that focus on the professed and reflected epistemological resources GTAs activate when engaged with facilitating student learning:

1. What "professed" epistemological resources do GTAs activate when talking about epistemology generally?
2. What epistemological resources do GTAs activate when reflecting on in-the-moment pedagogical decisions?

3.2 Background and Theoretical Framework

Within this section, I provide a brief introduction of the history of epistemology within an educational context and conclude with ways in which practice, epistemology, and professional development for GTAs have been studied.

3.2.1 Personal Epistemology

Personal epistemology has been defined as "the set of beliefs that individuals hold about the nature of knowledge and its production" (Sandoval, 2005, p. 636). Though this definition does not make reference to the nature of learning, Hofer recognizes that personal epistemology has a "powerful influence on learning" (Hofer & Pintrich, 2002, p. 13). In response to this influence, Elby argued that personal epistemology should not be so exclusive in its definition and should also include views on learning if the data suggests that epistemology is "inseparably entangled with views about learning" (Elby, 2009, p. 139).

There is a history of research of personal epistemology and its implications in educational psychology and education (Belenky, Clinchy, Goldberger, & Tarule, 1986; Hofer & Pintrich, 2002; Magolda, 1992; Perry, 1970) that has been extended to STEM contexts, particularly in physics and mathematics (diSessa, 1993; Hammer, 1994; Schoenfeld, 1983; Hammer & Elby, 2002; Speer, 2005, 2008). Personal

epistemology frameworks have traditionally been divided into three areas of study or models (Hofer & Pintrich 1997; Bendixon & Feucht, 2010):

- Personal epistemology as a developmental trajectory with individuals interpreting their experiences (Perry, 1970; Magolda, 1987, 1992; Belenky et al., 1986);
- How personal epistemology influences reflective and reasoning processes (King & Kitchener, 1994; Kitchener & King, 1981; Kuhn, 1991);
- Personal epistemology as epistemological belief systems or theories (Schommer, 1990; Schommer-Aikins, 2002, 2004; Hofer & Pintrich, 1997, 2002).

Common to these frameworks is a trajectory of epistemological growth from one that is naïve to one that is more sophisticated. Each framework also attends to who has authority of knowledge and the certainty of that knowledge. Traditionally epistemology has taken a unitary ontology, which is that epistemologies are inherent beliefs and do not change within a context. For an in-depth discussion on each framework, see Hofer (2001).

An alternative framework was proposed by Hammer and Elby (2002) in which they describe personal epistemology as a manifold construct that is composed of fine-grained elements called *resources*. Within this framework, *resources* may be categorized into the following (Hammer & Elby, 2002):

- Nature and sources of knowledge - knowledge as propagated stuff, knowledge as fabricated stuff, knowledge as free creation, knowledge as direct perception, and knowledge as inherent;

- Epistemological activities - accumulation, formation, checking, application, comparing, sorting, naming, counting, and adding;
- Epistemological forms - stories, rules, facts, songs, lists, pictures, categories, statements, words, names, and numbers;
- Epistemological stances – belief or disbelief, acceptance, understanding, and puzzlement.

These *resources*, when activated and reinforced by one another, form belief-like structures called *frames*, which are highly context dependent.

Hammer and Elby's framework for personal epistemology allows us to understand more deeply the choices that instructors make within a learning environment. Bendixen and Feucht (2010) suggest Hammer and Elby's conceptualization of *resources* and *frames* is "fundamental in establishing portfolios of varied instructional practices (i.e., a bag of epistemic tricks) that can be used to influence students' personal epistemology and, therein, to strategically foster their learning" (p. 12). The constructs of *resources* and *frames* also accounts for conflicting epistemological stances that may occur within an individual, which does not follow from a unitary perspective (Louca et al., 2004). Louca et al. (2004) claim that using *resources* will help to explain differences between "professed" epistemologies, stated views of knowledge and learning, and "enacted" epistemology, the inferred views of knowledge and learning by observation. The authors state that the difference between professed and enacted epistemologies is due to the contextual nature of their expression and the activation of different resources.

Similarly, Speer (2005) also challenges the literature that concludes there are differences between a professed and enacted epistemology. She argues that differences may be due to methodological issues rather than "an accurate reflection of the phenomena" under investigation. She claims that if the objective of a study is to examine the relationship between epistemology and practice, data on both must be collected concurrently rather than separately and then compared. Speer's suggestion then is to "begin with practices and gather data related to beliefs in connection with those practices and contexts (2005, p.372)." By gathering data concurrently, the instructor is given the opportunity to explain her/his practice in language known to her/him rather than a language imposed by a researcher and provides a less subjective interpretation of the connection between practice and epistemology by allowing the instructor to reflect on the context.

3.2.2 Practices, Epistemology, and Professional Development

Goertzen and colleagues have investigated in depth how graduate students think about and facilitate Tutorials in physics in order to improve professional development (PD) provided to graduate students (Goertzen, Scherr, & Elby 2009; 2010a; 2010b). Goertzen, Scherr, and Elby (2010a) indicated the importance of using fine-grained analysis, which Hammer and Elby's (2002) framework affords, to understanding practices within a Tutorial setting. Through interviews and observations of three GTAs, they found that although practices between the GTAs seemed similar, the belief structures behind the practices differed. This suggests that current observations and professional development may be not as effective if these differences are not taken into account. The authors saw this as a lack of "respectful

understanding" (p. 15) of the GTAs and pursued further research into how to incorporate GTA beliefs into professional development. Goertzen, Scherr, and Elby (2010b) suggest a *responsive* PD, which is "made possible when TA instructors create opportunities for TAs to express their beliefs and opinions and then tailor the PD to address them" (p.9). They concluded "we have to carefully observe and interpret [GTAs] practices and listen to their beliefs and experiences to learn about their ideas so that we can offer PD responsive to those ideas" (p. 10).

In mathematics, Speer (2008) investigated the connections between beliefs and practices of a mathematics graduate teaching assistant that facilitated small group work during discussion sections. The role of the graduate student was to act as a "facilitator and a resource" (p. 226) to the groups by circulating around the room and asking facilitating questions, similar to what the GTAs in Studios are asked to do. She determined that a fine-grained analysis of a "collection of beliefs" is useful to understanding how and what beliefs are influential in practice. Speer suggests that aspects of beliefs, such as those around teaching and learning, are intertwined as a facilitator makes "moment-to-moment" decisions in practice. One goal of her work is to add to and refine reform-oriented professional development programs through the fine-grained analysis of her work and calls for the use of methods that target the nuances between the interactions of beliefs and practice.

This study is based on the premise that learning and teaching practice are connected with the GTAs' views of knowledge, therefore learning is included in my definition of personal epistemology. With this added layer of learning, I seek to provide a thick description (Geertz, 1994) of how a learning environment is

experienced by a GTA. I use Hammer and Elby's (2002) contextual framework in this study. This paper builds on Smith, Sitomer, and Koretsky (2017) which investigates the following practices of two GTAs in a junior level thermodynamics course: attending to group dynamics, eliciting student thinking, and providing effective feedback to students (directive or facilitative). If we examine only the enacted epistemology through the practices of the GTAs, Dean and Jeff, we see similarities in the ways that they engage with groups as shown in Table 3.1. Both Dean and Jeff make sure to walk around the room, however their approach to engaging groups is different. Using Hammer and Elby's resources (2002) we can infer that both GTAs provide explanations and affirmations to student questions which is indicative of *knowledge as transmitted* and that procedural knowledge, such as *facts* and *rules*, are necessary to complete the Studio. However, Dean is more proactive in asking questions to groups instead of waiting for questions from students, which is what Jeff typically does. When Dean does interact with students, he typically asks questions or makes statements that appear to get students to think aloud and build on what they know (*knowledge as fabricated* and *formation*). Dean models this way of thinking for his students by making his thought process transparent as he makes sense of their question or how to respond. Many of the questions that Jeff responds to are students checking in to see if their work is correct. His approach is to look at their work and ask a question regarding their process. He often will outline or explain his process to solve or understand the problem in a procedural way (*knowledge is transmitted, rules,* and *facts)*.

Table 3.1. Summary of resources activated when observing GTA practice, enacted epistemology

Data Source	GTA	Epistemological Resources Activated
Video observation	Both	*Knowledge as transmitted, facts, and rules*
	Dean	*Knowledge as fabricated and formed*
Student responses	Both	K*nowledge as fabricated, knowledge is transmitted, formed, accumulated* and *applied*

While examining practices and the inferred enacted epistemology provides more information on what occurs in the learning environment, as Louca et al. (2004) and Speer (2005) suggest we can have a deeper understanding of the contextual relationship between epistemology and practice by investigating the professed and reflected epistemology of facilitators. Within this study, I identify epistemological *resources* evident in a professed epistemology of GTAs as well as *resources* that GTAs express when reflecting on teaching, learning and observations of their in-class practice. The purpose of my study is to make interpretations of GTAs' epistemology and start a conversation on how a deeper understanding of epistemology impacts practice in an engineering learning environment. This conversation and understanding will be a basis for the next step of investigating how to provide *responsive* pedagogical development.

3.3 Methods

This qualitative, exploratory comparative case study (Riessman, 2008) seeks to provide a thick description (Geertz, 1994) of two GTAs' epistemological frames. This study is part of a larger study that includes interviews and video recordings of practice from five GTAs over five courses in three disciplines. For this study, I selected two GTAs from the same junior level thermodynamics course. These GTAs

were selected since they engaged in their teaching practice from very different epistemological frames, and, therefore, provide interesting juxtaposed cases to explore the relationship between epistemological frames and practice within the same Studio learning environment. The analysis does not intend to judge what is "good" or "bad" practice or epistemology, but rather to provide a description of how epistemological frames and values graduate students bring into a classroom align with the choices they make in their teaching practice.

Data sources for this study included:

- Pre- and post- term interviews of the two GTAs focusing on past teaching experiences, descriptions of teaching style/approach, reflections on roles, motivations, and their expectations within the Studio space.
- Stimulated recall interviews (SRIs), where the two GTAs were asked to view themselves teach and then reflect on and interpret their pedagogical decisions.

I use the framework of Hammer and Elby (2002) to identify epistemological *resources* and *frames* GTAs profess, and reflect on when asked about specific episodes of practice (in-the-moment pedagogical decisions). I used pre- and post-term interviews to identify professed *resources*, and based on the suggestion by Speer (2005), I used SRIs to identify *resources* that emerged when GTAs reflected on their in-the-moment pedagogical decisions. Table 3.2 details the relationship between the research questions, data sources, and analysis.

Table 3.2. Research questions, data sources, and analysis approach

Research Question	Primary Data Source	Analysis
What "professed" epistemological resources do GTAs activate when talking about epistemology generally?	Pre- and post-interviews	Emergent coding using Hammer and Elby's resources and frames
What epistemological resources do GTAs activate when reflecting on in-the-moment pedagogical decisions?	Stimulated recall interviews	Emergent coding using Hammer and Elby's resources and frames, features of facilitating student learning

3.3.1 Setting

The implementation of Studios was part of a program-level course redesign aimed at increasing the frequency of interactive learning in the classroom (Koretsky, 2015). Within ten core Studio courses, a faculty member will instruct 150-250 students in a large-class setting. These students are then divided into multiple Studio sections of approximately 24 students; GTAs facilitate learning in Studios. This course structure is designed to present students with new information at the beginning of the week followed by opportunities to interactively engage with the concepts and with their peers during the week.

A GTA leads each of the Studio sections in the role a facilitator. In this role, they interact with students as they work in groups by noticing their thinking, asking guiding questions, and attending to interpersonal dynamics. Figure 3.1 shows the structure of the thermodynamics Studio course in this study. The course met in the large-class format with 199 students three times a week (Monday, Wednesday, and Friday) and in Studio with approximately 30 students on Thursday. In the Wednesday large-class meeting the Concept Warehouse, a technology-based interactive tool, was used to interactively engage students in conceptual learning (Koretsky et al., 2014).

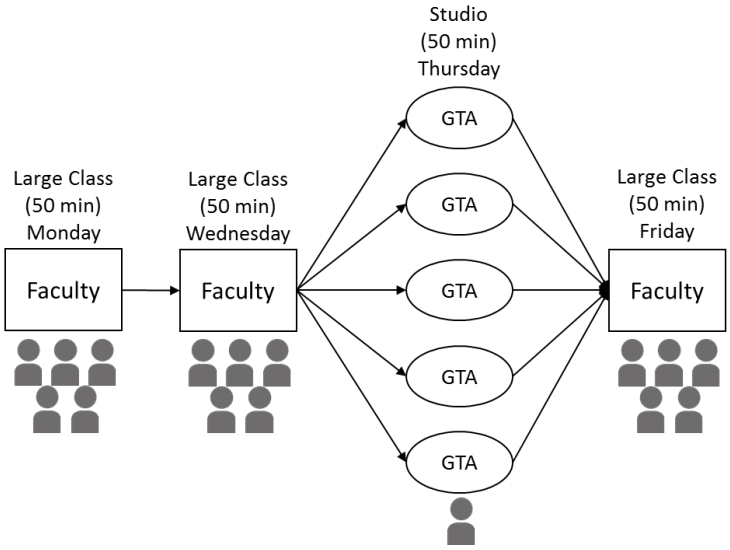

Figure 3.1. Structural design of thermodynamic course

The first Studio focused on the thermodynamics of mixtures. The Studio was broken up into three sections: pre-experimental, which focused on students setting up the experiment and making predictions; experimental, which asked students to perform a simple experiment and make observations; and a discussion section that asked students to discuss the major findings and perform calculations. Students were asked to answer a series of pre-experimental questions before performing a simple experiment. The second Studio focused on the fugacity of mixtures. This Studio was closed note, book, and calculator and required each group to turn in one solution. To motivate productivity, students were told that the group that got the furthest and had the most accurate solution would get a small amount of extra credit Studio points.

3.3.2 Participants

Two graduate teaching assistants (GTAs) were selected for the study. The first GTA, Dean (pseudonym), was in his third year as a chemical engineering doctoral student. As such, he had experience being a GTA in several Studio courses including this thermodynamics course his first year as a graduate student. Other courses he had

been a GTA for included a junior level heat transfer course, and senior level design and unit operations courses. In the thermodynamics course in this study, he facilitated three Studio sections, two of which were recorded. Dean received his B.S. in chemical engineering from a large research university in the south where he had previous experience being an undergraduate teaching assistant as well as a mentor for high school science students.

The second GTA, Jeff (pseudonym), was in his first year of a chemical engineering doctoral program. Jeff had one term of GTA experience in a sophomore level material and energy balances Studio course. During this study, he facilitated two Studio sections one of which was video recorded. Jeff had three years of experience as a chemistry tutor at his undergraduate university, also a large research university in the south. His role as a tutor included answering questions for students for a couple of hours a week in a designated space as well as one-on-one tutoring sessions.

Dean and Jeff both attended weekly meetings with the instructor of the thermodynamics course, an experienced educator and advocate of active learning, to discuss the upcoming Studio worksheet, practice in Studio, as well as work through possible misconceptions for students. These meetings also included conversations around exams and other administrative issues. During the Studios, the GTAs were asked to facilitate student learning through guiding questions based on the objectives of the Studio environment. The instructor of the course would regularly visit each Studio briefly to assess if the learning environment was consistent with the instructional and pedagogical goals. The GTAs also attended a GTA pedagogy seminar, which was a designated space for GTAs from all Studio courses to come

together and discuss their practice and concerns. The thermodynamics instructor the GTAs were working with facilitated this seminar.

3.3.3 Data Sources

Both GTAs participated in a series of interviews and video recordings through the term. Figure 3.2 indicates the designed timeline and data sources. For this study, pre- and post- epistemology interviews were used to identify general, professed epistemological *resources*. I used stimulated recall interviews (SRIs) to understand the GTAs' epistemological *resources* that were activated when GTAs reflected on their pedagogical decisions. Each data source is discussed in depth below.

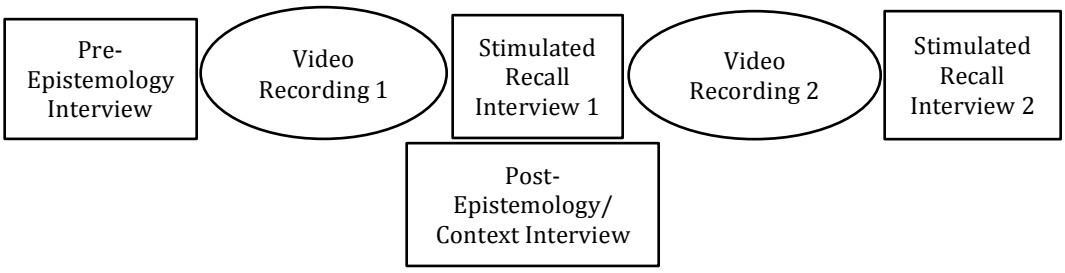

Figure 3.2. Designed timeline and data sources for study

3.3.3.1 Professed Epistemology Data

The primary purpose of the initial interview was to infer the GTAs' professed epistemological perspectives and determine their roles. The interview questions were based on the epistemological framework of Hammer and Elby (2002) and focused on the contextual nature of learning and teaching (see Appendix A for pre-interview questions). The pre-interviews occurred at different times. Dean's interview occurred during the second week of the thermodynamics course studied and Jeff was interviewed the term before. Dean's interview lasted 65 minutes and Jeff's lasted 75 minutes. The post-interview questions also focused on context and were initially

designed to be conducted at the end of the term as a standalone but were added on to the second stimulated recall interview at the request of the GTAs (see Appendix B for post-interview questions). Both Dean and Jeff's interviews lasted 63 minutes.

3.3.3.2 Reflected epistemology and practice

From the video recordings I selected a manageable number of episodes (5-7) for each interview. As part of the study design, around five episodes were thought to be suitable enough to provide rich information for the interview but not be over burdening to the interviewees. I reviewed each recording for episodes in preparation for the SRIs, selecting episodes that were representative of interactions between GTAs and students, instances when the GTA worked with groups of students in different or similar ways (Speer, 2005), as well as using Speer's "modes" of teaching as a guideline. These included (2008, p. 228):

- discussions with groups when students had completed a problem correctly
- situations when the facilitator detected an error in students' work before initiating a discussion
- situations when the facilitator detected an error in students' work during a discussion
- instances when students were struggling with a problem

Due to part of the room not being recorded, the second "mode" of Speer's guidelines, "situations when the teacher detected an error in students' work before initiating a discussion," were not included because they were not audible. The first round of episodes were shown to another researcher involved with the study, to determine which episodes demonstrated interesting GTA-student interactions. Prior to

data collection, this researcher and I decomposed the practice (Grossman et. al., 2009) of cooperative learning (Smith, Sheppard, Johnson, & Johnson, 2005) to guide our decisions of interesting, facilitated interactions. This included looking for instances of fostering functional group dynamics and eliciting student thinking. We also looked for how the GTAs responded to and implemented questions, such as responding to a students' question with a facilitating question, proactively asking facilitating questions, and how often the GTA explains or gives a direct response to a statement or question. These practices were then compiled into the three practices of focus: attending to group dynamics, eliciting student thinking, and the type of feedback GTAs provided to students (either directive or facilitative). From this initial set of episodes, five or seven of them were chosen to use in an SRI with the GTA.

SRIs were conducted between four to five weeks following a studio and were semi-structured to give the GTA latitude to talk about his practice. Table 3.3 describes the video recording and SRIs schedule. Each SRI had three stages. First the GTAs were asked to describe their classroom set up, their overall approach and engagement with groups, and a description of the Studio. Second, the GTAs were asked a series of questions on the episodes chosen, which were similar in scope. For each episode the GTA was asked to describe what he heard and/or saw in the episode, what he thought group members understood at different points in the episode, why he decided to engage in different ways. Other questions included if the GTA thought student questions were answered and whether or not the GTA would change his approach if given the opportunity. The final stage of questions asked about key concepts the students were struggling with in the Studio, how the GTA decided

whether to ask a question or explain to answer a student's question, and how this Studio compared to other Studios.

Table 3.3. Description of Studio recordings and SRIs

Topic of Studio	GTA	Week of recording	Week of SRI	# of episodes	SRI length (mins)
Thermodynamics of Mixtures	Dean	3	8	7	83
	Jeff	3	7	5	86
Fugacity of Mixtures	Dean	6	11	7	111
	Jeff	6	11	5	98

3.3.4 Data Analysis

All interviews were audio-recorded and transcribed. Emergent coding and thematic analysis (Riessman, 2008) were used to identify themes that would indicate *resources* and *frames* around teaching practices and learning. *Resources* guided the interpretation of the themes and ultimately the *frames*. *Frames* are the result of stabilized, activated resources and were determined by belief-like statements made across the multiple interviews and reflections. Pre-, post- interview data that were used to identify professed epistemology and the two SRI data to identify relationships between in-the-moment practice and epistemology were coded emergently and iteratively (Riessman, 2008) until each set of data reached saturation (Auerbach & Silverstein, 2003). A summary of resources identified was created for each GTAs' professed and perceived epistemology and checked with another researcher on the project.

3.4 Results

I answer each research question through themes found in each interview and identify *resources* within each theme. At the end of each research question I provide a table summary of all of the *resources* that are activated by the GTAs. Throughout this section *resources* are identified in italics and often come after a statement in parenthesis. It is important to note *resources* that are identified are contextual. I provide a *frame* for each GTA given the common *resources* that are activated within the Studio classroom and later discuss how these *frames* could be addressed through pedagogical development.

3.4.1 Research Question One: "Professed" Epistemological Resources

One aspect of understanding epistemology is to understand the perception of authority, autonomy, and who creates knowledge or fosters learning. To get at these concepts, GTAs were asked to describe what they believed their role was in studio, the instructor's role, and Jeff talked about the student's role. Both Dean and Jeff used the word "facilitator" to describe themselves and what they had been asked to do by the instructor. However their interpretations of what "facilitator" meant differed. Dean focused on facilitating students' learning of skills and how to use resources. Jeff focused more on what he was "allowed" to do when answering student questions and helping them work through the studio worksheet in a timely manner.

To further understand the epistemology of the GTAs in studio, they were also asked about their motivations and expectations, as well as those of the instructor's (Montfort, Brown, and Shinew, 2014). Below are deeper descriptions of the GTAs' interpretation of roles, motivations, and expectations within the Studio course. I asked

Dean and Jeff to describe their teaching style/approach to understand explicitly what they try to accomplish when they take on the role of a "teacher." Quotes used were edited for clarity.

3.4.1.1 Roles

Dean states that his role is to be a facilitator, saying:

> "So to use one of the hundred dollar words, I think my role mostly is as a facilitator. The way I think about it is I'm kind of trying to facilitate them [students] to use the resources that they have, which is their previous knowledge, their group, and all of their group members' previous knowledge. Sometimes it's even neighboring groups…or their textbook or anything…basically using all the resources that they have at their disposal to find a way to solve or find a way to work through what generally are kind of nuanced and intentionally challenging studio questions."

Dean believes his role is to help build up on students' knowledge and help them to use the resources available to them to construct that knowledge. This frame activates the *knowledge as fabricated stuff*, *accumulation,* and *formation* resources and focuses on the activity of constructing knowledge (learning) and answering questions, which come as the result of connecting previous knowledge. He later states that he wants students to conceptualize before application or procedure, which activates the activity of *application* as a resource. When asked if he sees himself in a teaching role, he discusses how he doesn't feel like he presents any new information, unless a student is unprepared and "any information about the topic is new information." He believes his role is more about the activity of knowledge creation in helping them to understand the question and realize and connect what they already know. He sees his role as fluid in the sense that he is a guide taking students on a journey and helping them construct knowledge and skills on the way.

Dean intrinsically believes that his role is to help others succeed. He also states that graduate students offer a unique perspective for the department in terms of new faculty hires or new courses, identifying that he has potential authority within the department and the decisions made there. For him, internal motivation, enthusiasm, and engagement help him to be a successful student. When asked about his role as a graduate student in the department, he states "…in general my role is not only just to contribute to my individual lab, but to kind of contribute to the success of not only graduate students, if possible, other students as well."

Jeff also states that his role is to facilitate, however he approaches facilitation in a different way than Dean, saying:

> "Yeah, so really like the big word is like 'facilitation' right? So like if they have a question you know, I'm not *allowed* to give them the answer, but I can you know, kind of work them up to the answer. You know, a good example of this would be like if they can't figure out how to calculate something, you know try to give them a general background of it, so like they can't calculate the force of pressure on something, I was like "Well what about another way of calculating that" you know "how would you think of it this way" or something like that. That, that's really what my role is, is to try to help them like step back and think of things…"

From this statement, Jeff implies that he is supposed to facilitate in the Studio, but it is unclear whether or not he buys into the idea of facilitation. He implies that his motivation is to help students procedurally calculate an answer, with a conceptual understanding as perhaps being secondary as evident by "if they can't figure out how to calculate something…try to give them a general background of it…" Within that same thought, Jeff goes on to say that his role is to help students "step back" and perhaps think of concepts in multiple ways. Resources that are activated within this idea are forms of knowledge being *rules* or *facts* that students grapple with, but also

asking students to engage in the activity of *knowledge formation.* It is unclear whether or not he believes that knowledge builds on facts or equations.

Jeff's use of the word "allowed" suggests that he doesn't feel like he has the autonomy to approach student learning in the way that he wants to within the Studio. He reflects that he was instructed not to give student's answers to questions and qualifies the types of questions he's not "allowed" to answer as check in questions, activating the knowledge related activity of *checking*, such as "is this answer right?" Not giving the answer to a student is difficult for him because that was what he was used to as a tutor. He struggles with aligning what he has been asked to do with his previous experience. He states that not providing direct responses is "difficult to deal with" and that as a tutor he felt like he had more "flexibility."

He reaffirms this sentiment in the following statement:

> "I would much rather be the instructor where I'm designing the course compared to being the TA that does all of the grunt work."

Implicit in this statement is that he doesn't think he plays as significant a role as someone designing the course or "teaching," that what he is being asked to do is seen as "grunt work." He later states "I really do like the idea of designing a class, so if I was in the position to design the worksheets or something like that, that would be fun." Jeff enjoys "trying to help others" and sees helping others as having authority to design courses or to provide answers.

> "I enjoy trying to help others, and you know I can do that in an office hour way, at least in the studio we can't… give answers and we don't design the worksheets and so we're almost like not even a role there except to just kind of babysit them and make sure they know what they're doing."

Again, Jeff struggles with not feeling as though he can give answers to students, indicating authority is wrapped up into a figure of a "teacher" not a

"facilitator." Not being allowed to answer questions directly, or *transmit knowledge,* means that he's not teaching students. What interests Jeff and at some level motivates him, is that he wants to teach a class, which to him means providing new information or "a foundation for learning" and designing the course in a way that he can "come up with what [he thinks] are better ways of helping kids learn." What is indicated in this statement is that he doesn't feel as though he has that freedom of finding ways to help his students learn within Studio, that he has a prescribed, straightforward role of not being able to do what he wants to do but to "babysit." Jeff's understanding of what knowledge is, the source of that knowledge, and how that knowledge is enacted or transmitted prevents him from exercising his autonomy of teaching within Studio and truly engaging in the practice of facilitation of learning.

3.4.1.2 Goals and Motivations

Dean's initial motivation or "ultimate goal" was to have all of his students pass the class, which is in conflict with how he continues to talk about his motivations and goals. He continues that he wants to have students understand material in an "in-depth way" and to feel like "they got something more out of the class than just a good grade." The belief that there is more to a course than grades is also reflected in how he approaches courses as a student. As a graduate student he states that his role is to be engaged with the course and to try and find something personally valuable. This stance of enculturating a deep understanding and interest in the material may be in conflict with the idea that he wants students to pass the course. Dean doesn't continue this line of thought at the moment, but addresses the importance of grades in a learning environment later in the interview when asked about what characterizes a

successful student. To him, a successful student is one who "understands the rules of the game" and approaches each class individually to determine what those rules are. This process includes determining what grade a student wants and then uses their resources to get it. However when he continues this train of thought, he ultimately states that as successful student uses resources, including studio and office hours, "if they're even the slightest bit not sure that they're understanding something." From this further explanation, Dean sees the grade as a tool to understanding and not the sole motivation for learning. In other words, a successful student is one that treats knowledge as something that is *accumulated* and/or *formed*.

Jeff's main goal within the Studio classroom is to get the main concept across to students so that they are "comfortable with the material," which will help them in the next course or on a test. He states:

> "I think the whole plan of going to studios is making sure that I'm somewhat comfortable with the material then I can go ahead and make sure that they're comfortable with the material. So that way you know, they can go into their next class or test or whatever they have you know, and know that concept from the studio."

This statement is ambiguous and could activate a variety of *resources*. Helping students to be comfortable with the material for future courses suggest *knowledge as fabricated, formation, application,* and *belief* towards the understanding of the material. However, this same statement could indicate activation of *knowledge as transmitted*. For example if Jeff is comfortable with the material, he can transmit that knowledge to students who will then be comfortable. It also may suggest the *fact* or *rule resources*, believing that knowing facts or rules will be what students need to be comfortable with the material now and in future courses. Jeff does not elaborate on

what "comfortable with the material" means and therefore it is unclear what epistemological resources he is activating.

3.4.1.3 Expectations

Dean's expectations at the end of a class is not that the students have finished the Studio worksheet, but that they "feel like they know more, they have a better feel for how to think about problems that are related to the topic or the focus in the Studio that day." He further states that if they are presented with a complicated problem in the future, that he wants students to be "better off" solving the problem after going to Studio. He also wants students to challenge each other and have learned how to use resources (e.g. each other, text, notes) to solve problems and "self-validate" their approach. His focus on deep learning and the *activity* of learning how to use Studio resources suggests he hopes to instill an internal motivation for student learning.

Jeff expressed that he expects students to finish most of the studio in the time allotted with some understanding of what they did. He creates expectations in the classroom by telling students that he "can't give [direct] answers" to student questions, that he won't tolerate cheating, and promotes the idea that although Studios are grade based similar to their homework and tests, they are meant to struggle through a Studio. Even though Studio is grade based, he states that students just have to show up and they'll get a good grade. Jeff focuses on the *product* of learning, such as completing the Studio or the grade rather than the process. This brings into question the *forms of knowledge* that are important in Studio, enough knowledge to get the grade (e.g. *rules* or *facts*) or knowledge of the relationships between concepts (e.g. *story*).

3.4.1.4 Instructor's Role, Goals, and Motivations

In regards to the thermodynamics course in this study, Dean said the following about the instructor's role:

> "I think the instructor's role is to reach the most, the greatest quantity of students possible within the given constraints of the circumstance. So in terms of a 10 week quarter, it's to try and get as many students as possible, not just the really, not just the ones who are always going to be engaged, but the students who are in the middle or the students who are in the lower end in terms of engagement or energy or whatever for the class, to try and get as many of them, meaningfully participating and meaningfully giving some kind of value of the course as possible."

He also stated that the instructor was to make sure that the "material isn't completely foreign to [students] before they come into Studio" or else he would have to take on a "teacher role." Within these statements, he goes back to the idea that the role of the instructor or himself is to have the students engaged in their own learning, that they are guides in the authorship of knowledge.

For the thermodynamics course, Dean primarily believes that the instructor's goal for him is to provide a new experience for students outside of lecture, which he states is "straightforward" and a place for "receiving information." Within this discussion Dean also states that this new experience in Studio is different than homework or lecture because it's not "individualized." Within these statements, Dean indicates that he sees a difference in the type of learning that occurs in the lecture and in Studio. In lecture, students "receive" information or *knowledge is transmitted* and individual. In Studio, *knowledge is created* and added on by engaging with other students. The expectation of the GTAs is that they are not "yes men or women" but are there to challenge the students and foster their learning so that they can answer

their own questions. Again, Dean attributes the authority of knowledge and knowledge creation primarily to students.

Jeff generally states that the instructor's role is to present conceptual material to the students so that by the time they come to Studio it should not be new to them. He states that the instructor "strongly believes in that, struggling through it to get actual conceptual understandings of what's going on." The language suggests that the Jeff might not necessarily agree with or adopted a similar way of thinking, which is reflected in the language he uses when he talks about what the instructor has asked him to do. Jeff frequently states that he is not "allowed" to give answers, which he believes is beneficial for student learning. This creates a tension between what he is being asked to do and what he states he believes is beneficial to student learning. For him, much of the authority lies with the instructor and not him or the students.

3.4.1.5 Teaching Style/Approach

Dean's approach to teaching is to connect and build students' current knowledge to work towards solving a problem. He states:

> "I would say that I'm always trying to make an effort to connect what they don't understand at the like, if they have a question about something, try to connect that back to something that's more derivative, and then try and get them to start there and then work towards what they don't know…
>
> … So in a perfect world I guess my role would be like lighting small fires all around the room and then coming back and like hoping that they had gotten bigger and if not then trying to. But it just never works out that way. "

This belief activates the *knowledge is fabricated*, *accumulation*, and *formation resources* and indicates that students are the creators of knowledge. This is his ideal, however he finds that he can be limited by time which results in him moving from

asking questions in response to questions, to being more direct and "nudging" them to use specific resources.

Jeff believes the best way of teaching is to help them with examples and then give different but similar examples to work on at home, activating the *transfer of knowledge resource.* He suggests that if he shows a student a procedure (e.g. *rules* and *facts*) that most students can do the problem on their own.

> "I like helping students along the way, so I personally like the best way of teaching, in my opinion, is to kind of set up the students, help them with examples, and then after that allow them to go home and figure out different, similarly designed exercises. You know, I think that's the most effective way for the majority of people."

This aligns with how he talks about types of students and a purpose of Studio. He states that recitations and Studios provide students the opportunity to not be "forced to go home and study" because they are given class time to study, which is beneficial to people who don't want to go home and study. Jeff also states that "there's not a right answer towards coming up with a good way to teach someone, it really just depends on how that person feels."

3.4.1.6 Interpretation of Professed Epistemology

Table 3.4 gives a summary of the resources activated for each GTA within the pre- and post-interviews. One of Dean's *frames*, which holds true across the different roles that he has, is that learning and knowledge creation is a social process/activity primarily authored by the students. This is evident by the frequent activation of the *resources knowledge as fabricated, accumulated, formed,* and *applied.* He also believes that learning occurs most successfully when students and instructors are engaged in the learning process. This partially stems from his approach to learning in

which there is an affective component. For him, being a GTA is "kind of an opportunity outside of everything else for me to like be reflective on, a different part of my personality that I wouldn't normally be if I was just sitting in the lab all day." Dean has also worked with the thermodynamics instructor before and had participated in several of the Studio pedagogy seminars and so his experience with and conversations around the Studio environment will have also impacted his views of learning and knowledge.

Within the interview, Jeff frequently made reference to and compared his work as a tutor to that of his Studio experiences. He is very much rooted in his experience as a tutor and how he personally learns material (e.g. through problem examples). The *resources* that were primarily activated when talking about teaching and learning generally included: *knowledge as transmitted, rules, facts, checking*. There is also ambiguity as to the activation of *knowledge as fabricated, applied*, and *formed*. For Jeff learning is primarily individual and occurs by showing examples and working through problems. Throughout the interviews he called his students "kids," and that he was not "allowed" to do certain things in the classroom. This discourse and activation of *resources* suggests that Jeff's *frame* is that knowledge comes from an authority figure and learning is primarily individual.

Table 3.4. Summary of the resources activated during pre-, post- interview, professed epistemology

GTA	Epistemological Resources Activated
Dean	*Knowledge as fabricated, accumulated, formed, applied, knowledge requires activity* Identifies contextual differences: in Studio *knowledge is fabricated*, in lecture *knowledge is transmitted*
Jeff	*Knowledge as transmitted, formed, checked, comes in the form of rules and facts* Possibly *knowledge is fabricated, formed, applied, and believed*

3.4.2 Research Question Two: "Reflected" Epistemological Resources

Stimulated recall interviews (SRIs) provide further insight and specificity into tensions between resources and better allows us to identify possible frames. They also provide a way to better connect aspects of instructional practices and complex engineering work. Frames result from stabilized resources across multiple contexts. Comparing resources across episodes within a Studio class session and across different Studio class sessions leads to identification of stabilized frames. The GTA reflections are first used to identify the resources that they activated and then to infer stabilized frames. While the videos of instructional practice form the focus of the conversation to identify frames and resources, reflexively, situating the interviews within the specific work of the GTAs are doing allows connections to be made between epistemological stances and instructional practice.

Since frames emerge across contexts, GTAs reflect on their practice in SRIs centered on two different Studios: 1) thermodynamics of mixtures during week 3 (SRI 1) and 2) fugacity of mixtures during week 6 (SRI 2). SRI 1 and SRI 2 provide different contexts in which the GTAs do their work. The first studio (SRI 1) centers on a physical experiment, the mixing of two fluids. The second studio (SRI 2) asks students to do mathematical work; developing an expression for the fugacity of a mixture given an equation of state. As such, the emphases are different. The first studio asks students to connect concepts and nomenclature to observation. The second centers more on procedural fluency, as they need to use mathematics skills to work through the Studio.

I used emergent coding to find general themes related to GTAs' instructional practice in Studio across these two different contexts. Themes include group dynamics, student characteristics, providing feedback and eliciting thinking, adapting practice and setting norms. These themes are used to identify resources within the reflections on practice for each GTA, which are then interpreted to identify frames. Finally, the frames are connected back to instructional practice through juxtaposing vignettes for each GTA. Vignettes are made up of the episodes that GTAs were show in SRI 1 regarding the Studio on the thermodynamics of mixing.

3.4.2.1 Attending to Group Dynamics

Dean identified types of students he frequently encounters in groups. One kind of student is the most vocal, or the "vocaltor" of the group. He states that this person might not be the most "apt" or the strongest student in the group but is not afraid to ask questions. Another type of student is one who will never talk. He factors these kinds of students into how he fosters group learning by trying to pick random students to talk or looking for disengaged members, or "group coherence." However he does recognize that he doesn't always pay attention to see if all members of the group are engaged. For this course, the instructor used the CATME Team Maker (Ohland et al., 2006) and for the most part, Dean did not identify teams that didn't work well together.

One of Dean's goals within the Studio is to have students use each other as a resource to construct their own learning (*knowledge as fabricated or transmitted*). He looks for students "asking questions of each other" which he states is an "effective way" to talk about different perspectives and solve problems. In one episode Dean

was shown, a student asked him a question, which another group member answered. To Dean this was a "particularly good" interaction between group members which is what he hopes will happen. Overall he believes that when students explain to one another it is beneficial, stating:

> "I think there's just, there's always more trust for whatever reason when your peers agree with you than if your instructor tells you something. I don't know. It's not always the case cause there's bad group dynamics sometimes and you get a person who the group doesn't trust or something like that or thinks that they just, making stuff up but, generally if I were to say something to a student, their initially reaction might be to ask a question back or to ask me why or to seek more validation, that I knew what I was telling them was correct, whereas if their fellow group mate says something to them I feel like there's less of burden of proof almost, for better or for worse. There's more of an inclination, a natural inclination for someone to trust the thing that their peer's saying rather than some, an authority figure is saying."

Again, Dean recognizes that although he can be seen as an authority figure, when the students are the authority of their own learning it is beneficial. To him, the *acceptance, belief or unbelief*, of the knowledge created is more effective if it comes from a peer. He also stated that is it "much easier to accept a mistake" if after working alone you have to explain what you did to other group members who might have approached the problem differently. He also doesn't mind if students work across groups so long as it promotes student learning. He stated:

> "I don't mind groups talking to each other, obviously if it's groups circumventing me by asking if they did it the same way, that's kind of not really cool, but if it's just they have an idea, or they're bouncing ideas off one another, that's really not a problem."

Dean adapts how he interacts with groups based on the objective and content of the Studio. In Studio 2 where students are asked to use mathematical concepts to create an expression for mixtures, he noticed that in some groups students would work individually on different steps of the problem and then come together to check

their work. While in general, he notes that he would encourage students to work together, he believed this method was more beneficial for students.

Jeff described how the physical space of the Studio impacted group dynamics and his facilitation. His Studio room had long tables in rows with minimal walking space in-between tables. Jeff described his room as a "bowling alley" and a "lecture style classroom" that made it difficult for teams to collaborate. Students did not typically create groups by turning their chairs around to face other team members; rather they created groups linearly down the table. Jeff stated this was a disadvantage because "if one person is sitting here then the person in the middle is getting all the interaction, but then maybe one on the side is going to struggle to interact…"

He also said that in such a closed space groups would interact with one another. This interaction across groups was evident within several episodes chosen. There were two groups who sat next to each other and interacted consistently. Jeff acknowledge that two women in different groups were friends and would often talk to each other throughout the Studio, stating "they're pretty much the same group." He spent a significant amount of time with these two groups and while he said it wasn't ideal for groups to work together, he would not interfere if a group member was explaining correctly to the other members.

Jeff discussed his frustration with intergroup interactions by saying it "really isn't supposed to happen but it's hard to really force that…" He described one instance where a student had the wrong answer but convinced several other groups that he was correct despite Jeff indicating it was incorrect and explained the correct path forward. This not only impeded the progression of the students in the Studio, but

it also put in to question the authority of Jeff. Particularly after the instructor came into the room and provided the same correct explanation that Jeff had provided earlier. In another instance, a student turned around and started explaining a concept to another group, Jeff explained:

> "I don't want to tell them stop talking to each other, so I just let him go ahead and explain it. And you know, he's actually good at explaining things so it's not a big deal, I don't like it though when other ones, so [student] will tell people answers, and I've seen it before too like, there was a conceptual question like 'does the temperature go up?' and he'll be like 'it goes up' to somebody who asks him a question, and I, after it's done I mean I can't say 'take back what you said.' So I mean, but it's pretty difficult to be walking around and not allow anybody to give away answers."

In a sense, Jeff decides which battles to undertake when dealing with intergroup dynamics. At times he allows students to talk across groups when it's productive and members are "engaged," other times he is unable to stop students from providing each other answers to closed ended questions. However, he at one point states that a student "gains experience" by answering questions.

When asked how Jeff approaches groups he described how he asked questions, trying not to focus his question on one person but the whole group, and looked to their worksheets to gauge where they were. He expects the students in the groups to be

> "…talking to each other, everybody should be involved, and they should be able to at least come up with some type of answer for the question. Whether or not it's right or not, and then they can ask me for clarifications on things."

Jeff wants members in a group to be working "collaboratively" rather than "watching." He states that to get students involved he'll ask "what do you think specifically?" However, episodes show in the SRIs did not indicate that he did this in

practice. However, when reflecting on a certain episode, he did notice that he didn't engage a student the way he "should" have by asking a question and making sure the group was involved. He also makes the decision to focus on struggling or "ostracized" groups rather than those he believes work well together.

Jeff said students know they should be interacting, but individual personalities can get in the way of that interaction or engagement. He said about group members talking with one another:

> "…some people just don't have the personality to work in groups and they kind of have the wrong attitude towards it too, they don't even try to do it. They just get through it or get around it. So I mean sometimes that happens but for the most part, I think both of my classes are pretty good."

He believed that intentional grouping provided students with the opportunity to work with others they normally would not. However he also noted that communication across cultures was difficult eventually saying that intentional grouping "may be better it may be worse." Regarding communication, after watching an episode of a group he noted that one group member, who was an international student, had tried explaining a correct answer to the other group members who didn't understand him. The other group members then turned to the GTA for help.

Jeff discussed limitations when trying to facilitate groups in Studio. First he noted that he was not able to get to all groups, which would be problematic if a student convinces others of a "wrong answer." In this case, he is not able to correct wrong explanations unless the group asks a question. When reflecting on a particular group that worked well together he stated:

> "…I'm focused on helping these guys and maybe they did something wrong but you know, they would never know cause I was never able to get to them, since I noticed that they were working more with each other the whole time, so, and they may never ask a question. I mean I would still

> walk around and see them but I wouldn't be consistently going through their work, so if they turn the page and they started working on something else, and there's something wrong on that page, you know I'm not going to stop their work and ask them if they got something correct. So there are times where that happens where some of the better groups get things wrong compared to the groups that struggle cause they don't ask questions, and they make some silly errors or something like that."

This quote indicates that he approaches groups reactively rather than proactive. As part of his practice, Jeff leaves groups that are working well alone and focuses on those that he believes need more attention. He does not detail why he does this, but it could be due to time, student personalities within the classroom, or an underlying resource that *checking* in with him in the form of a question, means that students need help.

3.4.2.2 Student Characteristics, Perceptions, and Understanding/Thinking

Dean talked about different types and goals of students he has encountered in the classroom. As mentioned before, he recognizes that within groups he interacts with students who are vocal and ask a lot of questions and students who don't speak, including those who understand or don't understand the material. He also identified another type of student, one who does well and has strong opinions saying, "when you have students that do well they, they have stronger opinions, they're less willing to accept an answer." He suggested that some students don't listen and others will just listen to him at the beginning of Studio rather than read the Studio worksheet. One student motivation behind questions he noted was that students are looking for very specific answers to move on and not necessarily want the meaning, or explanation, behind the answer stating "[u]sually people are looking to get a certain amount of information." From this statement, Dean recognizes that students are approaching him

with epistemological resources of *checking* and that knowledge comes as a *fact* or *rule* that is *transmitted*. He partially accounts for this by believing that students don't understand the purpose of Studio. For example, students think work needs to get done to get the points, or that they need to finish the Studio and it's the GTA's job to help them do that. He also stated that students believe the content is more complicated due to the fact that it is thermodynamics. To deal with this he noticed that students try to connect what they do know with something that they want to know even if the thinking is incorrect.

Jeff described some students who when they get stuck, instead of moving forward, wait for him to come and help. He said:

> "…that's the absolute worst thing that you could do. And then if there's three other people that have that same problem, then I can't get to all of them at the same time so they should at least either think of something they could do, or maybe move to another part of the Studio and see if they could figure out what they would do at that part. So at least they're being somewhat productive and not just waiting for me."

This fall back to an authority figure suggests students are operating under a transmission model for learning and have not developed the skills or motivation to work effectively within their groups. The lack of utilizing or working with peers could be due to group make-up, personality as Jeff has suggested, norms that have been established and reinforced in the Studio, or that students just expect the GTA to provide answers based on experiences in other courses. Jeff further expounds on the idea of authority in the classroom when talking about an experience already discussed above in the "Attending to group dynamics" section. When the instructor comes into the room Jeff believes that students ask him more questions because the students know Jeff is not "allowed" to provide answers and so they think "maybe they can get

away with more questions" with the instructor. Jeff implicitly voices his frustration with not being able to provide the feedback that he wants to students.

> "So that kind of happens sometimes when, I think people do get frustrated with that, where they don't understand how to do the question and then they try to do it one way and then we don't give enough feedback to tell them that it's either right or wrong, so then they struggle with moving on to the next section, or always worried about whether they're right or wrong."

Jeff's understanding of the frustration of the students reveal underlying ideas about learning, that there is a right or wrong answer, and that not providing direct confirmation is hindering the students' ability to learn (*knowledge as transmitted*). Jeff stated he has to earn the students' trust by correctly answering questions. In the end however he stated "I could be the smartest person in the world but if I'm a TA and the professor's there, they're still going to trust the professor over me." Again, there is a strong theme that knowledge comes from and is *accepted* by an authority figure rather than the student or the group.

Jeff acknowledges that there is

> "…a lot of hatred towards [the instructor's] methods of Studios and us [GTAs] not being able to tell them answers, or give them feedback on stuff. So I think a lot of [students] tend to just not ask questions or they'll ask a question and then I'll try to give them something to think about and then they'll basically be like 'alright, well that didn't help me. I'm going to just do what I was going to do anyways.'"

Within this statement Jeff indicates that students are frustrated that he isn't allowed to tell them direct answers as part of the Studio pedagogy. This was a sentiment that Jeff held across all of the interviews and came up frequently in his responses, at another point saying students have " a lot of hostility towards" Studios. He suggests that students would rather the Studios were in a tutorial format where they "come in, we give them a problem and we show the how to solve it," which is

indicative of a *knowledge as transmitted*. However, he continues saying "that [showing students how to solve problems] may be a decent way of learning, but it's not a concrete style of learning…" He does not expand on what "concrete" means but he recognizes that there is a more robust way to learn other than through solving problems by example.

Characteristics in students that Jeff identified included:

- Students who do well in the studio care less about the structure of Studio and whether or not the GTAs give answers or not
- Students who understand the grading system will just put in effort to get their grade in Studio and then try to figure out the answer at some point
- Student confidence can hinder learning by preventing them from asking questions or double checking their work for "little mistakes"
- Students can overcomplicate problems or need reassurance

The prior term, Jeff facilitated a studio with sophomore students and he made comparisons between them and the juniors he worked with in the thermodynamics course. In relation to Studio 2, which was the derivation Studio, he stated that sophomores participated in Studios "somewhat lazily" and that the juniors worked hard. For both Studios 1 and 2, Jeff suggested that as juniors they should know basic chemistry and mathematical content and use that prior knowledge (*knowledge as fabricated*). He stated that "they're in this program for a reason" suggesting they have the skills to move forward.

For Jeff an indicator that a student or group has understood an idea or concept is a through a verbal confirmation such as an excited "oh okay!" or an explanation of

that concept or idea. He also indicates that he knows some level of understanding occurs when a student is able to "recite" back to him what he said (*knowledge is transmitted* and *understanding* comes through recitation). When a student answers "somewhat hesitantly then I probably didn't [answer the question] and I try to ask them more about it but some people could also be like 'oh whatever, I'm just going to try and figure it out myself' or something…"

When asked about whether or not a particular group would be able to figure out a problem, Jeff said probably not individually but they could with others.

> "If I hadn't been there, probably not. If they had friends I think at some point they would be able to. Just a couple of minds working together, at some point they'd be able to, but if they were individually locked in a room, and they were at this point in their education, they had not gone to lecture after this, I think they would've had a very difficult time. It may have been anybody could, they're in this program for a reason, I mean I think maybe they could've at least some point, figured something out but, I thought, I think that they would have a very difficult time figuring it out."

Jeff suggests that students can learn by working together with others but does not state how this is achieved. Previously he stated that students learn by going through examples and by explaining to one another.

3.4.2.3 Providing Feedback to Students and Eliciting Student Thinking

Dean expressed he will be more direct in answering questions rather than asking facilitating questions due to time. He checks the pace of the groups by walking around and using the worksheet as a visual marker to help him decide how to move forward. He will compare this group pace with an "appropriate" pace based on an "average team" working through the Studio. This pace is important to his practice because he monitors which groups need more help based on where they are on the

worksheet. If a group is not on pace, depending on time, he will be more direct with his answers. He explains:

> "…when it starts to get to the last few groups then usually it gets hard to be as thorough about my facilitation rather than my answer giving. As much as I can I'll attempt to be a facilitator."

He will give more direct answers to move student thinking past a hurdle that's not the conceptual point of the studio or if he believes the Studio is "hard." For example, in Studio 2 students are asked to derive a fugacity equation, which involves completing a double summation. When interacting with a group, he noticed students were solving the problem using a concept that was not helpful for the students to use so he tried to "redirect" them into thinking about what the question was asking them to do. While going through his work, he noticed they missed a concept even earlier and tried to address it. He states:

> "And this was past the point now, I think where I wasn't holding or I wasn't facilitating their understanding of the double summation as much as I was just trying to explain to them what double summation means and then hope that they would realize, okay so then this is what went wrong. So still kind of not telling them okay your answer should be, this, plus this, plus this. But telling them a lot more than I would otherwise."

Within this interaction, Dean moves to being more direct in an effort to *transmit* information to make up for a missed application earlier. In contrast to this, Dean will also leave groups with enough information to move forward but not too much information before he steps away, he will also let students try and fail before giving them a hint (*knowledge as fabricated, formed, and applied*). For example:

> "…usually the reason why I move away from a group has either to do with not wanting to give away too much information or wanting them to spend more time talking about it as a group, and less time me telling them stuff, or because there's eight groups that have their hands up and I'm only one person. It's usually a balance between those two things."

Dean asks facilitating questions to "get students to think" about multiple concepts. Within interactions with groups and students, he wants them to understand the "why" or the big picture of a problem. Dean also will reframe the question or hope that they pick up on "context clues" that are embedded within the Studio worksheet questions. He tries to reframe through his explanations or use facilitating questions when students are struggling. For example, Dean recognized a student was struggling with a particular concept stating:

> "It was surprising to me that she immediately recognized that they're both polar molecules and then didn't put that together that that was important, she immediately went back to like "oh they're both polar molecules" and "so why is that important?" and she's like "cause they mix well!" and it's like "that's not the answer to the question, that's not an explanation! That's just putting two things that are separate together." So that was why I was kind of scrambling here for like 40, 45 second to try and think of a way to get, to frame polarity in such a way that she could understand the importance of it in terms of the explanation to part b here, in terms of intermolecular interactions."

Dean identified polarity as an important concept for the Studio. However, he identified some issues with using facilitating questions: a "misconception" can get lost in the line of questions and that being vague might be interpreted by students as being an affirmation of a "misconception." Dean states he listens for misconceptions while he is walking around the Studio classroom. He will be more direct in his response to hearing a misconception in order to "lead them towards thinking about what they just said critically." As he engages with groups, he states that he wants to listen and doesn't want to be a part of the conversation unless necessary. He stated, "I don't want to jump in when I don't need to" indicating that he gives the authority to the students.

When Dean interacts with students, he acknowledges and interprets student thinking in the moment; he knows his students well enough to gauge individual thinking. Reflecting on an episode he said "I wanted them to kind of explain it to me to make sure that I, they understood it the right way." To connect with students Dean also uses examples on the fly that he believes are useful to his specific audience at one time calling them a "thought experiment." He also references prior courses and concepts within his explanations. When talking with students Dean makes his thought process transparent by thinking out loud with them. He hopes he is modeling how he wants his students to think, but wishes he was more "concise." To him, "concise" means he has had time to refine his thinking and is therefore able to communicate it more clearly.

Jeff stated that he goes into Studio to ask questions, check their papers for progress by walking around, and be a facilitator by not giving answers. In response to student questions, he will explain concepts in different ways. When reflecting on a specific episode he stated:

> "I really, I'm not entirely sure what she's struggling with cause I tried to say it a couple of different ways, but it really kind of, it just, it seemed like she was over complicating it…I guess she just wasn't listening to what I was trying to say."

Here he recognizes that different explanations would be beneficial to students struggling, but in the end he puts the onus back on the student by suggesting that if his explanations did not make sense, it was because the student wasn't listening (*knowledge as transmitted*).

In a particular episode, Jeff responded to a student question by giving the student space to think out loud. He stated, "I wanted him to let himself explain so I

wanted to make sure he was explaining." Later on he responded that the student may have been slightly confused but "once he was able to bring it out into words he probably understood it himself." This practice suggests that Jeff values student explanations in relation to their *understanding*.

When asked how Jeff decides to answer a student question with a question or explanation, he gave the following response:

> "I'm almost always responding with a question. Just in general in here, the only time that I would actually start explaining something is towards, like you saw, in the last ten minutes of studio when they still don't have it and they've asked four different ways of asking it, and then I realized at that point it may not be worth it to continue to, progress them, just give them the, a little bit more insight on what they need to do."

Jeff will leave students at a place where they might not be able to answer the problem yet, but can move forward. This decision is in part so he can get to other groups, but he believes part of his role is to provide more "insight" into the problem to help students move forward. "Insight" to him included students recognizing the "real problems" of Studio, students' further understanding of how equations came to be, or him providing another perspective to approaching or solving a problem. He knows some students well enough to be able to gauge when he can be "lazy towards answering" questions and let them "figure it out." He continues this sentiment of letting students figure it out in the following response:

> "I mean there's also some hesitation but I don't want to, you have to kind of let them struggle a little bit, like you can't walk away feeling like they know exactly what to do. I mean, they have to be able to somewhat figure some of this stuff out. So I felt like I did enough to move on to the next step and then you know, if they struggled with that, then they would have to ask me another question."

Jeff's process for helping groups is incremental. He will respond to students questions, but feels it is necessary to leave them to find the solution themselves

before coming back to help them. When reflecting on an episode with a student struggling with a concept, he stated:

> "…my intention is, at least if I'm doing that incrementally it's not a big deal because they're thinking about it, they're not getting it, they're thinking about, they're not getting it, but I don't want to be giving them the answer and then they just know how to do everything from then on in…"

Within this statement there are two conflicting epistemological resources being activated. The first is that *knowledge is fabricated* and that if Jeff helps a student think through a problem incrementally, then he's moving the student's thinking forward. However, in the second half of the statement Jeff indicates that if he just gives the students the answer "they just know how to do everything from then on in" which activates the *knowledge is transmitted* resource. The theme of showing students how to solve a problem comes up frequently throughout the interviews and is talked about in more depth in the "Epistemology" theme.

3.4.2.4 Adaptation of Practice Based on Student Feedback

Dean suggested that he is reflective during and after studio. During Studio, he will gauge how examples or explanations make sense to students, indicating that *application* is important. An example of this was he tried using a "more natural" example for his students to think about because they were on the "cusp of understanding and they [were] hung up on something." The example appeared to confuse one group of students further, or didn't achieve what he was hoping it would. He tried the same example with another group with similar results. From the confused feedback from the students, he decided not to use the same example again.

Throughout the interview Dean gave similar examples of incorporating feedback and adapting his practice based on student understanding.

At one point during the term, students were giving pushback on the design of Studio and he took that opportunity to explain to students the purpose of Studio. He heard what his students were saying and took the time to respond in class saying "I will try to be more effective in giving you information so that you feel like I'm being more valuable in the time that I'm here." At this point he explicitly told his students that he purposefully doesn't put grades on the Studio worksheets so they don't focus on the points, rather as a place to practice what they don't know. In regards to after Studio, he wished that his Studio sections would be farther apart so he would have time to decompress from the first Studio and prepare for the next.

Jeff also adapted his practice based on student verbal and nonverbal feedback. The verbal feedback he paid attention to was the "nature" of the question being asked by a student. When reflecting on an episode, Jeff pointed out he changed his line of questioning because he "noticed that she had a difficult time" with his explanation, so he asked a different question. Through interactions with students he realized that they were struggling on a particular concept and so he started to become more direct with his answers, stating:

> "…toward the end of the Studio I started to realize this is a problem [referring to a concept that students struggled with] and started giving more help on that."

Similar to Dean, Jeff will be more direct in his responses to student questions in order to help students with misconceptions due to time or if students are really struggling with a concept. He also is more direct so students don't do more work than is necessary (*knowledge is transmitted*). For example, Jeff stated he "was telling them

[students] answers for the summation part because I wanted them to get that, cause the real part of the studio was try and do the derivation." He later indicated that the "summation part" was something the students could "figure out on their own" so he just got them started. Within this example, Jeff is making a decision of what information is necessary to move forward and which concepts are basic or needed to solve the problem. He provides another example of this rationale by giving more direct answers so students did not "do more work than necessary" because it "defeated the purpose" of the Studio. While he is more direct in some circumstances, he also stated when reflecting on a particular episode that he would chose to not to tell students they were "wrong" because it would let them know what the correct answer was. In this reflection he also said "I figured that would be a good opportunity to let her explain to them what she did." In this case he takes on a more passive role and provides the space for the students to engage with one another.

3.4.2.5 Studio Design and Space (Setting Norms)

Dean believes the purpose of the Studio is to get students to interpret and use past knowledge to solve a problem. He believes that Studio is designed to help students struggle with material so it will help them out on homework and tests, where the bulk of their grade comes from. He stated that if students are getting all of the points in studio but still failing the exam, then they aren't "getting anything out of Studio."

Dean does the following to set norms within Studio:

- Moves desks into triangles
- Explicitly explains the studio design and purpose

- Reinforces that he won't give direct affirmation e.g. "you're correct"
- Reinforces that he wants students to prove understanding through explanation by asking them to explain their responses
- Steps away from a group indicating he wants them to discuss in the group (non-verbal communication)
- Does not give students a score on their Studio paper so they don't focus on points

One interaction Dean hoped would become a norm is that students would present him with a solution rather than asking him questions.

When reflecting on an episode from Studio 1, Jeff noticed that students were struggling with a calculation. He opines that for this particular Studio students were able to calculate parts correctly and get all of the credit but might not have understood the content until the end of the Studio. He noted for Studio 1 that it focused on nomenclature and calculations, which should have been "straightforward" for the students.

For Studio 2, Jeff believed the Studio was procedural and required more of an understanding of mathematical operations rather than thermodynamic concepts. However he acknowledged that it would provide students with the opportunity to model something. He also stated for this particular Studio, that there was one correct answer and multiple ways to do it wrong. He was very focused on the process of going from one equation to the next (*facts and rules*), he did not necessarily engage with students on why a certain application or substitution of a variable was important to understand.

An aspect of the Studio 2 design that Jeff mentioned was that it allows students more time to deal with complex problems, more so than if they were taking a test stating it would be more "straightforward" on a test. This idea of struggling on a complex problem in Studio hints at Jeff's understanding that one purpose of Studio as a reformed learning environment is to provide students the opportunity to struggle with peers in a low stakes environment. He does not detail any further ideas around this particular purpose of Studio.

One way in which Jeff sets norms in Studio is by making announcements during Studio about expectations of participation. He also believes that by the time the students are juniors they are used to the Studio environment and ask better questions. He does not expound any more on ways that he sets norms.

3.4.2.6 Interpretation of Dean's Reflected Epistemological Resources and Vignette

Dean expressed explicitly and implicitly views he had on learning. In Studio 1 students were asked to perform an experiment as part of the Studio. When reflecting on this, Dean said that that a purpose of Studio is to "connect more of your senses" and that it was helpful for students to not only think about the Studio concepts theoretically, but physically as well. He noted that there are multiple ways of thinking about a problem and that there is no one correct way to solve a problem. He encourages multiple pathways,

> "I also kind of recognize part of that was me recognizing that they were doing it three separate ways and kind of telling them that that's a good idea and that they should continue doing that."

This statement was in response to reflecting on Studio 2, however he also stated that "math is much more black and white" and that "mathematically there's

kind of always a right way." In Studio 1 he believed that the experimental nature of the Studio triggered in the minds of student their chemistry courses, which may have gotten in the way of their thinking about the problem. These two ideas indicate that there is a contextual nature to knowledge that can be triggered based on physical set up, framing of the problem, or the application of specific tools e.g. the quotient rule. Students struggled with the mathematical concepts and application in Studio 2. For Studio 1, Dean noted that students struggle with taking what they know and applying it to another "thing that's kind of like it but not really." While Dean believes that *knowledge is constructed* he stated:

> "I think sometimes it's hard for students to want to leave their class that they're currently working on to reach back into material. I think most people retain a very small percentage of the stuff that they they've done in a course."

To combat this idea of students not wanting to *transfer or connect knowledge* across courses, he suggests students break down a concept into components that they do know (*knowledge is fabricated from rules, facts,* and is *formed* and *applied* through construction). An example of this epistemological frame is Dean was confronted with a question that he didn't have an explanation ready for so he thought through the question by having the students break down the concept into components and put them together.

Multiple times throughout both interviews, Dean suggested that asking students to verbally explain their answers is beneficial to their learning, that communicating ideas is indicative of *understanding* when not "regurgitated." To Dean, the *formulation* of knowledge is triggered when students take in information and are able to explain it in their own words. He stated:

> "… not explaining it back to me in the exact way I said it but in their own way. I think to me if a student can explain to me in a way that makes sense to them then they understand it because they're not just regurgitating what I'm saying, they actually have to kind of come up with the words themselves."

Engaged learning to Dean is when students are utilizing all of the resources they have available to them including books, notes, teammates and an instructor to bounce ideas off of. This reinforces his epistemological frame that learning is a social endeavor and that *knowledge is fabricated*.

After certain episodes, I asked Dean if he were in the same situation again, whether or not he would do the same thing or not. His responses included:

- "More or less" with the explanation that he believed he performed one aspect of his role as a GTA Studio instructor which is to check in with all groups;
- He would change the initial way he approached a student question;
- He wanted to be more "concise" in his explanations;
- Or he would act in a similar way.

Overall, Dean seemed satisfied with his facilitation and when asked to reflect on how to handle the situation again he primarily stated he wanted to refine his practice. While discussing his practices, Dean centered the learning onto his students. Dean's *frame* is that learning and knowledge creation is a social process/activity (through explanations, peers as resources) that is authored by the students who approach problems in multiple ways (there is not one right way to understand a concept, explain a phenomenon, there are multiple ways to do engineering, and multiple sources of knowledge). Common resources that were activated in his reflections of practice as stated throughout this section are *knowledge as fabricated*

stuff, the *formation, accumulation, and application of knowledge* and the stances of *belief and unbelief, acceptance,* and *understanding*.

Vignette of episodes from SRI 1 regarding the phenomena of mixing

Below are four episodes of Dean interacting with students regarding the first Studio on the thermodynamics of mixing. These four episodes center on the concept of the best way to mix two substances of varying densities. Dean was shown each of these episodes in his SRI 1 interview and indicated that density was one concept that students struggled with in Studio 1. The other concepts Dean identified students struggled with were the change in temperature and volume when two substances were added and the relationship to polarity and the partial molar volume of water. Dean has four episodes, compared to Jeff who has one, because Dean made the decision to ask students to explain to him the pre-experimental activity before collecting materials and performing the experiment.

Episode 1: Physical vs. Chemical

Student asks a question about eight minutes into Studio 1.

S1: Should we assume perfect mixing for this?
D: I think that that's something you guys have to decide on. But that's a good question though.
S2: Well I was thinking that you'd probably want to put the water in first cause it has a smaller molecular mass, so more water molecules…
D: Okay.
S2: …and then ethanol is going to be bigger, so there's less ethanol molecules in 40 mL. So there'd be more effective mixing if you have, pour the water in first.
D: I think your line of thinking is good, think about what might be more important than the mass of the molecular.
S2: Like the hydrogen bonds or something?
D: So, go away from chemical and think more physical. But you're on the right track.
[walks away]

Episode 2: Turbulence

Dean is reacting to a student question. This episode occurs nine minutes into Studio 1.
S1: Do we just go grab them [the experimental materials]?
D: Oh yeah, once you guys have completed the first page, yes so I'm actually, before you start I'm interested in what you think?
S1: We think you should add the ethanol first cause water is denser…
D: Okay.
S1: …and when you pour the water in it'll create more turbulence and create a better mix.
D: Um, I think that's really good. I think, turbulence might not be the right way to describe it…
S1: Well more of like, it'll churn it…
D: So if you have, density is a good way to think about it. So if you have the less dense, add the less dense thing in first and then add the more dense thing, what would happen?
S1: …it'll want to sink through it. Yeah.

Episodes 3 and 4: Oil and vinegar analogy

Dean responds to a student question 11 minutes into Studio 1.
D: Question?
S1: For which one should we mix first? We said that the ethanol should be mixed first and then the water because it's denser.
D: Okay, so that line of thinking is totally good but, so then why? What about the density makes mixing better? So like what's the…
S2: The larger number of…
D: So I mean, so what I'm asking is…
S1: Why is density…
D: So why do you use density, what about the property of density is going to make the mixing better? So like if you have something that's less, you're saying to put the less dense thing in first right? And then you add the more dense thing…
S1: [makes churning hand motions]
S2: It's heavier so it'll like float to the bottom…
D: It's more dense.
S1: Is it about the volume?
D: Um, so well I'm trying to, so density is a good way to think about it, like but what I'm trying, I guess what I'm trying to ask is why is density important? So if you have the less dense material, and then you're adding the more dense material on top what's gonna happen? What happens when you add something that's more dense to something that's less dense? When you put it on top of?
S1: They mix better!
D: Okay, so if you just had ethanol and water and I put it in a jug and shake it up, what's gonna happen after an hour?

S: [indiscernible]
D: What happens if I take oil and vinegar and I put it in a jar?
S2: They'll separates…
D: They separate right? And that also has to do with density right?
S1: Oh yeah. They separate because they cannot mix up or when they…
D: It's true but the separation happens because of the difference in densities right? So if you add something that, if you were to take in this case the vinegar put it in first and then you add the oil on top, which is what you're suggesting to do right? Then what would happen to the oil? Would it sit on top?
S2: No. It would sink.
D: It would sink. So…
S1: They will mix.
D: Yeah, if it's sinking through right?
S1: Ohhh!

Dean is responding to a student question about fourteen minutes into Studio 1.

D: What's up?
S1: Which one do we pour first? We were thinking of the densities of them…
D: Okay.
S1: …and ethanol is less dense so we're just confused on, like we're looking at it two different ways.
D: Mhmm.
S1: So if water is more dense you would pour, and for example you would pour water first then ethanol next. It's not going to go down all the way I feel like…
S2: Ethanol is just gonna, settle on top…
D: Right. So this was, I, an analogy I was trying with the other group. So take a similar situation, a little bit different, but oil and vinegar right? So they don't mix because of other reasons, but also because they separate because of density, kind of what you're suggesting right? So if you have vinegar in a container and then you add oil on top of it, what's gonna happen to the oil?
S2: The oil's gonna sit on top I feel like…
D: Which one's more dense? The oil or the vinegar?
S1: The vinegar.
D: The oil.
S1: The oil's more dense?
D: Yeah.
S1: Oh.
D: So maybe poor, poor analogy but it worked for them. I was trying. So then think about that, so just think about it abstractly then. So if you have

a less dense fluid, you pour the more dense fluid on top, what's gonna happen?
S1: More dense?
D: To the more dense fluid? It's going to go to the bottom. What happens in the reverse case, if you put the more dense fluid on the bottom and put the less dense on top? So which one, allows them to mix better?
S: The ethanol first then the water on top, that way yeah…
[walks away]

Each of these episodes center on the same concept, however students have different views of how to explain or understand the phenomenon of mixing: chemical vs. physical and turbulence, where Dean suggests the analogy of oil and vinegar. Within the first two explanations of chemical vs. physical and turbulence, the students bring these ideas to Dean who then acknowledges the thinking and tries to facilitate and build their thinking to another direction. Within the final two episodes Dean presents an analogy to students in an effort to help them understand the concept of mixing in terms of something they might be familiar with. In all of these episodes Dean eventually asks the question "what would happen if you put a more dense fluid on top or a less dense fluid?" after some discussion. We see within his facilitation the enactment of his frame that students are authors of knowledge and that there are multiple ways to understand and explain a concept.

3.4.2.7 Interpretation of Jeff's Reflected Epistemological Resources and Vignette

Throughout the interviews, Jeff provided insight into what he believes learning and knowledge to be. As was discussed under the "Student characteristics, perceptions, and thinking/understanding*"* section, Jeff has conflicting views as to how learning occurs. On the one hand he made statements that support a *knowledge is transmitted* resource such as "I don't want to be giving them the answer and then they

just know how to do everything…" or understanding comes from being about to "recite" back what he said or going through examples. He indicates there is a source or authority of knowledge outside of the student. This also activates the *knowledge as a fact* resource. On the other hand he also recognizes that students providing an explanation of concepts help student understanding and cause them to be more comfortable with the content, which centers the student as the producer of knowledge. He also stated that a decent way to learn is students being shown how to solve problems procedurally like in a "tutoring session" but it is not a "concrete style of learning." This statement is ambiguous but suggests that procedural learning is one process to learning but there is a more solid way to achieve that understanding by some other process he does not identify.

For Jeff personally, he states he can recall concepts through solutions, or that you can piece together concepts with a guide saying "I know enough of the concepts to be able to teach it to someone after I see solutions cause I haven't seen it in a really long time." For Jeff a guide was the solution to the Studio worksheet, however it could be the textbook, notes, other students, or an instructor. He also is activating the *knowledge as fabricated* and the knowledge related activity of *application* resources. Students learn by bouncing ideas off of others or a TA and need to struggle. Jeff also briefly brought up how teaching philosophy influences practice. He stated:

> "I guess it depends on your kind of teaching philosophy whether or not it's better to just give them the answer or let somebody else help them through it."

Again, student learning is decentralized to the instructor and his/her teaching philosophy.

Throughout the interview Jeff also indicated what he believed his role to be, which included:

- Being a facilitator who doesn't give answers, asks questions, and lets others give the answer
- Clarify things
- Get students to solve the problem
- Provide reassurance
- Keep everyone on track, complete the Studio worksheet

After some episodes I asked Jeff if he would act in a similar way if he were in the same situation again. In one instance he focused on preparation and often not feeling prepared to facilitate in the way that he wanted to. For example he stated:

> "If I was specifically in that situation again, I probably wouldn't do anything different. But if I was able to prepare for it, I would probably, I'd probably would've come up with, so I didn't get a chance to like work through this, we briefly discussed it in our meeting. I probably would've liked to have worked through it to see more of where students may have gotten a problem with it, and then at least, I would've had more of a starting point on where to describe what problem they had. So that would probably've been the biggest difference, really for all of the clips that you've shown, having the ability to know exactly what's stopping them before trying to answer their question, would be really helpful."

In another episode he would change making a mistake in answering a question and would have asked students a question to get them to think about a concept. After another episode he said "I probably should have asked her a couple more questions to see if she could figure it out herself." Observations from the video reflect this comment as Jeff is more prone to answer a question with an explanation rather than a series of facilitating questions. As noted earlier, he also noticed that he didn't get the

group involved and would have asked a question to the whole group to make sure they were all involved.

Jeff is rooted in his experience as a tutor and how he learns material; this is reflected in his responses around student learning and understanding. Resources activated through the interviews included *knowledge as transmitted*, *knowledge as fabricated, checking, application, rule, fact, and acceptance*. Jeff focused attention on who has authority within the implementation of Studio and what he felt he was "allowed" to do. He would often refer to the students as "kids." Within the observations, Jeff's answers to student responses were very procedural and this carried over to the interview questions. He was very direct with responding to SRI questions and didn't expound on his thinking or why he did something unless specifically prodded. The SRIs also confirm Jeff's *frame* that knowledge is transmitted from authority and learning is primarily individual. Jeff is also more contradictory in his statements than Dean is.

Vignette of episode from SRI 1 regarding the phenomenon of mixing

Below is one episode of Jeff interacting with students in the first Studio. This episode focuses on the concept of mixing two substances of varying densities. Jeff was shown this episode in his SRI 1 interview and stated that general mixing and dimensional analysis were the concepts that students struggled with in this Studio.

Jeff stops and listens to a group of students discussing the Studio worksheet and proactively asks a question. This episode happens nine minutes into Studio 1.

S1: The ethanol should be poured into the water right?
S2: Yeah.
J: Why do you think that?
S1: Because…

S2: Because if you do it the other way, it's gonna blow up.
S1: Yeah, well it'll, no…
J: Blow up?
S1: Not blow up, but it'll start reacting, like right when the, I feel like if you pour the ethanol into the water it'll start reacting right as you, er add the water into ethanol, right as you start pouring, but…I'm not exactly sure but I think that the reaction will be…
J: Well there's not going to be a reaction right? Cause water and ethanol don't like, react.
S1: Well not react but like, like the molecules will like, I mean I don't know [laughs] I don't know how to describe it honestly.
J: So if you were like trying to, let's say you were trying to mix something right?
S1: Uh huh.
J: What would you pour first? The stuff that would sit on top or the stuff that would sit on the bottom?
S3: Oh, so we consider the density of water.
J: Right, yeah.
S3: Which one is bigger? Is larger?
S1: Doesn't ethanol have a smaller density than water?
J: Yeah, ethanol's lighter right? It's like point…
S2: So is that more or less than water?
S1 + J: Ethanol's less dense.
S2: So wouldn't you…
S1: …I guess you'd pour the water into the ethanol then.
J: Right.
S2: So it mixes while the ethanol is there.
S1: Yeah… [pause] but isn't there like a reaction, it produces a certain amount of heat doesn't it?
J: But it's not a reaction, it just mixes right?
S1: Yeah.
J: If it was a reaction then something would chemically be changing.
S1: Yeah. But I don't know what you'd call that?
J: It's mixing.
S1: It's just mixing? Yeah.
J: Cause you can separate it completely.

Within this episode Jeff facilitates students to the concept of densities in a direct manner and moves on. It appears that students are struggling with the concepts of chemical reactions and mixing which he directly addresses and the end of the conversation. Jeff's directness is an indication of his frame that knowledge is

transmitted. Within his reflection on this particular interaction he stated that he believed that the students struggled with idea of mixing and reacting, but that after he "told" them they understood.

Table 3.5 provides a summary of the resources that were activated during the SRIs for each GTA, and common resources.

Table 3.5. Summary of resources activated during the SRIs, reflected epistemology

GTA	Epistemological Resources Activated
Dean	*Knowledge as fabricated, knowledge as transmitted, formed, applied, rules, facts, understanding, acceptance* Students are more likely to *understand* and *accept* knowledge from peers. Student *understanding* is *formed* through explanations.
Jeff	*Knowledge as fabricated, knowledge as transmitted, applied, rules, facts, understanding, and acceptance* Students are more likely to *accept* knowledge from authority. Student *understanding* comes from explanations and recitation.
Both	Choose to be more direct, which leans towards *knowledge as transmitted*, when responding to student questions due to time or student misconceptions.

3.5 Discussion

I frame the first part of the discussion by comparing Dean and Jeff's epistemological *frames* regarding the three practices of attending to group dynamics, eliciting student thinking, and providing feedback to students (directive or facilitative) studied in Smith, Sitomer, and Koretsky (2017). I provide pedagogical suggestions for practices within a Studio context and I address interesting contradictions that were exposed through the stimulated recall interviews (SRIs) including:

- A discussion on the differences and similarities between Dean and Jeff's activation of *resources* towards student *understanding*.

- The differences between Dean and Jeff's *frames* and how that relates to who they believe *understanding* and *acceptance* of knowledge comes from

Table 3.6 provides an overall summary of the resources activated by each data source, including resources that came from observations of practice or an enacted epistemology (Smith, Sitomer, & Koretsky, 2017). The frames that the GTAs studied bring to their work in Studio contrast starkly. Dean generally sees learning and knowledge creation as a social process (explanations, peers as resources) that is authored by students who can approach conceptual understanding and procedural fluency in many ways (there isn't one right way to explain a phenomenon, solve a problem, or to do engineering, there are multiple sources of knowledge and solution paths). On the other hand, Jeff generally sees knowledge as hierarchical and transmitted from authority and learning as primarily individual. In addition, Jeff more frequently activates resources that are contradictory to those identified in other contexts. Dean and Jeff's juxtaposing frames can be used to understand their differing choices in instructional practice in Studio. Connecting epistemological frames to instructional choices leads to more general implications for those working to shift curricula towards complex instruction.

Table 3.6. Summary of all data sources and epistemological resources activated

Data Source	GTA	Epistemological Resources Activated
Video observations (Smith, Sitomer, & Koretsky, 2017)	Both	*Knowledge as transmitted, facts, and rules*
	Dean	*Knowledge as fabricated and formed*
Student observations (Smith, Sitomer, & Koretsky, 2017)	Both	K*nowledge as fabricated, knowledge is transmitted, formed, accumulated* and *applied*
Pre-, post-interviews	Dean	*Knowledge as fabricated, accumulated, formed, applied, knowledge requires activity* Identifies contextual differences: in Studio *knowledge is fabricated*, in lecture *knowledge is transmitted*
	Jeff	*Knowledge as transmitted, formed, checked, comes in the form of rules and facts* Possibly *knowledge is fabricated, formed, applied, and believed*
Stimulated recall interviews	Dean	*Knowledge as fabricated, knowledge as transmitted, formed, applied, comes in the form of rules and facts, understanding, acceptance* Students are more likely to *understand* and *accept* knowledge from peers. Student *understanding* is *formed* through explanations.
	Jeff	*Knowledge as fabricated, knowledge as transmitted, applied, comes in the form of rules and facts, understanding, and acceptance* Students are more likely to *accept* knowledge from authority. Student *understanding* comes from recitation and explanations.
	Both	Choose to be more direct, *knowledge as transmitted*, when responding to student questions due to time or student misconceptions.

3.5.1 Attending to Group Dynamics

Dean's *frame* identifies students as the creators of knowledge and that learning occurs socially, however this does not transfer to a regular practice. Students said he did well getting to all of the groups but also that he needed to improve this

practice (Smith, Sitomer, & Koretsky, 2017). The student response data focused on the larger activity of circulating the room rather than what was happening in individual groups. From the video observations, he did not often explicitly or implicitly (1% of occurrences) ask students to work together or defer questions to other group members (Smith, Sitomer, & Koretsky, 2017). He pointed out in the SRI that he doesn't always pay attention to other group members when responding to a question so he is aware to some degree that there is room for improvement in this practice. Jeff also received similar mixed student responses in regards to his practice of making it to all of the groups. However, Jeff's *frame* indicates that students can learn from each other, but an authority figure holds all of the keys. Similar to Dean, he did not spend much of his time getting students to turn to one another (3% of occurrences) (Smith, Sitomer, & Koretsky, 2017). Jeff focused limitations of his practice to the physical space of his Studio, but did not go in-depth into how that impacted his facilitation of individual groups. He noted that he doesn't like groups to interact because they can spread misinformation. When asked about how he approaches groups, he said he would ask questions, which is not visible within the observations.

Although Dean and Jeff have different epistemological *frames* as to how learning occurs and who is the author of that learning, they enact similar practices. Both Dean and Jeff indicated that they know their students well enough that they tailor their practice to their students' personalities. Knowing students' personalities and how they interact within a group is a useful tool for facilitation and could be an area in which to focus pedagogical development. Overall, creating reflective

facilitators improves practice (Ghaye, 2010; Henderson, Beach, & Finkelstein, 2011). We need to provide opportunities for GTAs to reflect on how they engage group members and allow them to practice different types of approaches to attend to status within groups (Horn, 2012).

3.5.2 Eliciting Student Thinking

On the surface, Dean and Jeff take different approaches to eliciting student thinking. Dean will say, "I like that line of thinking, keep going with it and I'll come back" and Jeff will encourage students to "finish what you're saying" as a student explains a concept. Both however, believe that asking students to provide explanations of concepts is beneficial to their *understanding*. One difference is that Jeff also believes that students understand a concept when they can "recite" it back to him. Recitation denotes repeating back facts and is not as productive as asking students to make sense of it in their own words. One of Dean's practices is to model student thinking by thinking aloud. To build this practice, a topic within a pedagogical seminar should be metacognitive thinking and how to model by asking questions (Tanner, 2012).

3.5.3 Providing Feedback to Students

In regards to the practice of providing feedback to students, it was interesting that both GTAs activated *knowledge as transmitted* in a response to contextual limitations. Initially this would be seen as a less productive practice within Studio if you were to solely infer an enacted epistemology for both GTAs. However, both GTAs expressed that time and student misconceptions played a role in deciding how to respond to student questions and whether to be directive or facilitative. Dean and

Jeff are also negotiating their own motivations and goals for students when making this decision, although they do not explicitly tie the two together. Dean wants to help students make connections to what they already know and encourage students to use each other as a resource. However, as stated previously he does not enact this *frame* effectively in practice. Jeff focuses on helping students understand the concepts and finishing the studio. For Jeff, being directive would be more pressing and seem more effective to achieve this goal. While finishing the Studio is a motivation for Jeff, it is not an important aspect of the Studio pedagogy. The GTAs were given opportunities during the term to meet with other Studio GTAs to discuss experiences in the classroom. While this was important to creating community and provide an opportunity to be more reflective, not all Studio GTAs attended nor was there a focus on specific practices and the theory behind those practices. Ideally time would be spent on the main theories behind the Studio pedagogy, such as introductions to social and interactive learning theories, as part of a pedagogical development seminar or course. Knowing when to be directive or facilitative builds upon the skill of eliciting student thinking and depending on whether or not the epistemological frame favors social learning, it also builds on the practice of attending to group dynamics.

Another practice that Dean and Jeff reflected on was fostering students in the zone of proximal development, or helping students perform a task they would not be able to complete without guidance (Hall et al., 2006; Wass, Harland, & Mercer, 2011; Shabani, Khatib, &Ebadi, 2010). Again, a motivation for Dean is to help students make connections and Jeff states he takes an incremental approach to responding to student questions. They are scaffolding but do not recognize it or use that language.

This is a practice that should be fostered but carefully. Scaffolding requires an interaction between a more central community member with one who is on the periphery (Lave & Wenger, 1991). With Dean's *frame* that student learning and acceptance comes from social interactions with peers, he would have to be able to identify a group member that understands a concept more fully to guide the discussion or continue using scaffolding questions and improve his practice of getting group members to ponder together while he steps away. With Jeff, his *frame* centers knowledge coming from an authority figure which is contrary to a collaborative, community approach to scaffolding. One way to help GTAs prepare for this practice is to have an ongoing conversation with the instructor of the course as to what concepts are important. Asking GTAs to engage as facilitators we can focus on explaining the nuances to decision making, such as how do you know when to transmit or be more direct with information as opposed to facilitate, and ask students to construct it on their own? Preparation needed for this would include input from the instructor as to what concepts are important but also focusing efforts on developing GTAs pedagogical content knowledge (Hill, Ball, & Schilling, 2008).

If we only exam the relationship between enacted and professed practice, Dean's epistemological *frame* of actively engaged student centered learning is more consistent across enacted and professed epistemology. However there are contradictions between the activation of the *resources knowledge is fabricated* and *transmitted*. Students indicate that Dean does well at explaining ideas and observations indicate that Dean will give direct answers, which suggests *knowledge as transmitted* (Smith, Sitomer, & Koretsky, 2017). When reflecting on his practice,

his reflected epistemology, he accounts for these different activations by acknowledging the constraints of the Studio environment such as time and the misconceptions students bring with them into the classroom. Dean has more experience facilitating within Studio and therefore impacts how he talks about it and possibly why he is more reflective in his practice. This is a skill that effective instructors will use. Jeff appears to be less consistent and unsure in his practice and enactment of *frame* that learning is individual and effective through example problem solving learning. However like Dean, he elaborates that some of his decisions are based on constraints within the Studio. Jeff's reflections were very procedural and did not provide the same amount of nuance as Dean's reflections. This may be indicative of Jeff's *frame* crossing contexts.

From a trajectory perspective of epistemology (Perry, 1970; Magolda, 1987, 1992; Belenky et al., 1986; Hofer, 2001) Dean's frame is indicative of a more sophisticated epistemology with Jeff's frame suggesting a more naïve one. A core component of epistemological literature is who has the authority of knowledge. For Dean, students are central to knowledge creation whereas Jeff defers knowledge coming from an authority. This is important to understand when creating *responsive* pedagogical development because it details a core component of epistemology, who has the authority of knowledge creation, that can inform how we approach moving frames of authority from naïve to more sophisticated. Dean and Jeff's frames are inferred from within the context and reflection of their teaching practices in a Studio environment. Their reflection on the context and practices within that context indicate how important it is to understand the nuances of how a GTA negotiates their

epistemology with classroom constraints. Hammer and Elby (2002) and Speer (2008) provide the framework and methodology to highlight the need to understand context and negotiation in relation to epistemology and practice that other models do not afford.

3.6 Conclusions and Future Work

The purpose of this paper was to illuminate some of the complexity of epistemology and practice within a Studio learning environment through identifying *resources* and *frames* that GTAs enact, profess, and reflect on as in-the-moment decisions. The motivation behind this paper is to start a discussion on how to capture nuances in practice and epistemology and how that can translate into pedagogical development for GTAs. I used the practices of attending to group dynamics, eliciting student thinking, and providing feedback to student questions to frame the discussion. These are practices that have been shown to be effective for student learning.

In this study GTAs were placed in a complex learning environment and asked to implement a complex practice. In regards to their enacted epistemology, both appeared to favor explanations and clarifications which indicate the activation of *knowledge as transmitted*. The professed epistemology presented further nuances and provided information to construct a *frame* for each GTA. One of Dean's *frames* that came from the data was that learning and knowledge creation is a social process/activity primarily authored by students. Jeff had a *frame* that student learning is individual, transmitted through examples, and the primary source of knowledge comes from an authority figure. These *frames* held true when analyzing reflections on episodes of practice, however motivations and other *resources* were activated that

provided a fine-grained understanding of how GTAs are making pedagogical decisions. I provide suggestions for pedagogical development such as providing opportunities for GTAs to be reflective and practice questioning, introducing topics of metacognition, social and interactive learning theories, and scaffolding.

3.7 Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. DUE 1347817. The authors also wish to acknowledge Devlin Montfort. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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3.9 Appendix A – Pre- Interview Questions

1. Where are you from?
    a. Why did you come to [University]?
    b. What degree are you seeking? Why?
    c. What are your goals after graduating?
2. Please tell me about your previous teaching experience.
    a. How long and in what capacity?
3. Tell me about your teaching duties as a GTA.
4. When do you typically find out about your assignment as a GTA?
    a. Does this affect how you approach the course?
    b. If you found out earlier, how or would you prepare for the class differently?
5. Walk me through your typical studio (recitation, laboratory) experience.
    a. How do you prepare for studio (recitation, laboratory)?
    b. What are some challenges that you face? What are some of the challenges you're your students face?
    c. What aspects of studio (recitation, laboratory) do you believe is beneficial for you as an instructor or student? For your students?
6. Describe your teaching style/approach.
    a. Has this changed from when you first started?
7. Have you noticed a difference in student behaviors from your different classes, for example their preparation or general attitude towards the material or you as an instructor?
8. Describe to me what your role in studio (recitation) is.
9. Describe to me what you believe the instructor's role in studio (recitation, laboratory) is.
    a. How often do you communicate with the instructor? How does this communication typically occur?
    b. Describe your interactions with this instructor.
10. Do you see variability between the instructors you TA for? Could you describe?
11. What do you enjoy most about being a TA?
12. Do you have any fears or doubts around being a TA?
13. Describe your students.
    a. Do any particular groups or common characteristics stand out?
    b. Describe an interaction with students you felt really helped the student/team.
    c. Describe an interaction with students you felt was particularly challenging.
    d. How do you know if your students have learned a concept?
    e. What kind of differences do you see among your students/among groups of students in studio (recitation)?
14. Do you have other roles on campus?
    a. Please describe.
15. If they identify as being part of a research team:

    a. How do you approach your research?
    b. Describe the type of interactions you have with your advisor.
    c. What do you enjoy most about being a researcher?
    d. Do you have any fears or doubts around being a researcher?
16. How do/did you study for your [major] classes?
    a. Is that consistent across all of your [major] classes?
    b. What about other classes outside your [major]?
    c. What is the best way to study for your classes?
        i. Is this how you study? Why or why not?
    d. Has the way you study changed since you were an undergrad? If so how?
    e. How do you know if you have learned a concept?
17. In what ways do you identify with your students and notice similarities between their experience and your experience as a student?

3.10 Appendix B – Post-Interview Questions

1. What goals or motivation do you have within the classroom?
2. What are your expectations, if any, at the end of a class session?
3. What norms and expectations do you set in your classroom?
    a. What is this based on? (departmental norms, past student experiences, etc.)
4. Are there any teaching techniques that come more natural to you now than when you first started? (noticing…)
    a. How did this happen?
    b. Did you receive any support regarding teaching techniques?
5. What tools do you typically use in class? (pay attention to language in the video)
    a. Have these changed over time?
    b. What did you wish you had?
6. Are you willing to try new things?
7. What characterizes a successful student?
    a. What does a successful class look like?
    b. How do you believe you are successful as a student?
8. How might your teaching differ in a different classroom environment?

9. What struggles have you encountered with your students (and the instructor)?
    a. How has that impacted your relationships?
10. How often do you reflect on your experience as an undergraduate student when teaching?
    a. How does that affect you as a graduate student? As an instructor?
11. What do you believe your role is within the classroom?
    a. Within your program (department, school, etc.)?
        i. Your students' role?
        ii. The instructor's role?
12. What do you see as benefits or rewards to being a GTA?
13. Describe your connections with other GTAs both in the department and outside of the department.
    a. How and to what extent does other GTAs' work impact you?
14. Do you interact with any others concerning issues of curriculum, teaching, and learning?
    a. [If yes] Please provide detail regarding those interactions, including
        i. who,
            1. Are these people in your discipline?
        ii. how often,
        iii. regarding what specifically
    b. What encourages or discourages these types of interactions?
15. At the end of this experience as a GTA, what do you expect to gain or lose?
16. How and to what extent, does being a GTA factor into your identity?

4. A Graduate Student Pedagogy Seminar in Chemical Engineering

Christina Smith, Ann Sitomer, and Milo Koretsky

Submitted to *Chemical Engineering Education*

4.1 Abstract

Graduate students are often asked to facilitate undergraduate student learning but lack the necessary preparation and understanding of complex classroom practices to do so effectively. We assessed the current pedagogical preparation provided for chemical engineering graduate students at Oregon State University who are asked to teach in Studio settings. This article describes the creation, implementation and reception of a pedagogical development seminar, and offers suggestions for those who hope to create or implement a similar seminar in their programs.

4.2 Introduction

Teaching is an important but often challenging activity for graduate students. In the role of graduate teaching assistants (GTA), they impact the learning experience of undergraduate students, but they also gain a set of knowledge and skills beyond what they learn in class or through research. Typical duties for GTAs vary and can range from conducting problem solving sessions, creating homework solutions, grading, and holding office hours. GTAs may also find themselves working within pedagogically sophisticated learning environments such as working with small groups of students in a Studio setting, as we have recently reported (Koretsky, 2015; in review). Within these spaces GTAs are asked to "facilitate" student learning. By "facilitate" we mean that they are encouraged to shift activity, as much as possible, away from directly showing students how to do their work to asking students questions, eliciting their thinking, and encouraging group interactions.

As such pedagogical strategies become more complex, the professional development of GTAs becomes critical. While graduate students are familiar with

negotiating a course as a student, they do not have experience with facilitating student learning and typically lack the proper pedagogical preparation prior to entering the classroom to be effective. *Chemical Engineering Education* has published reports on courses devoted to improving graduate students as researchers and writers (Ollis, 2016) and to graduate certificates that require voluntary participation (Baber, 2004), but there is limited information on pedagogical development of graduate student teachers. In an ongoing effort to prepare incoming graduate students to be a facilitator in Studio, researchers on a NSF WIDER grant integrated pedagogical development content into a new professional development seminar in the School of Chemical, Biological, and Environmental Engineering (CBEE) at Oregon State University (OSU) during the 2016-2017 academic year. This paper describes the creation, implementation, and reception of the seminar, and offers suggestions for those who hope to create or implement a similar seminar in their programs.

4.3 Background

4.3.1 History of CBEE Pedagogical Development Seminar

This study was part of a National Science Foundation (NSF) Widening Implementation and Demonstration of Evidence Based Reforms (WIDER) grant, titled Enhancing STEM Education at Oregon State University (ESTEME@OSU). ESTEME@OSU focused on improving instructional practices within five STEM units (chemical engineering, biology, chemistry, mathematics, and physics) and understanding the impact of evidence-based instructional practices (EBIPs) in the classroom on performance and attitudes of students. The primary EBIPs of interest on this grant were interactive engagement in lecture and cooperative learning in Studio-

type environments. GTAs within the five STEM units often serve as facilitators in these cooperative learning Studio environments. In the five units, we found a wide range of pedagogical development opportunities to prepare them for complex teaching practices.

Table 4.1 provides an outline of the major activities and products that eventually resulted in the integration of pedagogical development into the year-long seminar for first year graduate students. During the 2014-2015 academic year, researchers attended and characterized professional development opportunities provided to graduate students in chemical engineering, biology, chemistry, mathematics, and physics to understand how graduate students are being prepared for the implementation of EBIPs within small group learning environments. Opportunities for pedagogical professional development for graduate students ranged from pre-term orientations, weekly seminars, teaching planning meetings, reflective practice meetings, and involvement with curriculum and assessment development. Biology, chemistry, physics, and mathematics all included pedagogical development opportunities in seminars that were part of the core graduate curriculum. In CBEE, GTAs were asked to attend bi-weekly meetings that focused on creating a community that reflected on problems of practice and discussed alternative ways of approaching practice. These bi-weekly meetings were voluntary and organic in nature, such that topics differed week to week and generally were directed by issues the GTAs were currently facing.

Table 4.1. Details of the major activities and progression for pedagogical development in CBEE

Timeframe	Activity	What we learned or accomplished
2014-2015 academic year	Characterization of current pedagogical development provided to GTAs in five ESTEME@OSU units	Need for a structured pedagogical development for GTAs in CBEE
2015-2016 academic year	Interviews and observations of GTAs in CBEE	CBEE GTAs: • were unprepared to facilitate in Studios • used pedagogical language but not necessarily adapting/adopting practices • wanted opportunities to practice communication with students • did not fully understand how to interpret the nuances of student responses and questions
Summer 2016	Attended the NSF sponsored CoMInDs workshop	How to design and implement pedagogical development for graduate students using existing resources, frameworks, and structures
	Convened a meeting of community members interested in pedagogical development within CBEE, College of Science, and the Graduate School for input on goals and direction	Revised goals and received input on important skills graduate students need
2016-2017 academic year	First iteration of pedagogical development seminar sessions embedded in a professional development seminar series	• Devote a significant effort pedagogical development integrated into pre-year activity and into the graduate seminar • Focus on the topics of facilitating group work, metacognition, feedback, and the diversity of students • Create engineering specific pedagogical instructional videos

Through the 2015-2016 academic year, researchers interviewed, observed, and recorded graduate students in CBEE, mathematics, and physics to understand the beliefs that GTAs have about teaching and learning and how they enact teaching practices in the classroom. One purpose of this research was to design a structured, integrated pedagogical development specifically for GTAs in CBEE that addressed specific learning goals, which will be discussed below. An initial analysis of the

interviews and recordings showed that GTAs felt: underprepared to facilitate in Studios, were using pedagogical language but not necessarily adapting/adopting practices, wanted opportunities to practice communication with students, and did not fully understand how to interpret the nuances of student responses and questions. We determined that further pedagogical preparation for GTAs to facilitate Studios was needed in CBEE to attend to these initial findings.

In June 2016, two of the authors attended the three-day NSF-funded College Mathematics Instructor Development Source (CoMInDS) workshop. The purpose of attending this workshop was to prepare for and build on current frameworks for pedagogical development. The workshop focused on how to design, improve, and implement a graduate student pedagogical development program. While at the workshop, we developed goals for the pedagogical development for graduate students in CBEE. These goals aligned with the concerns brought up in the interview and video research, but we also wanted further input from members of the community and others who had expertise in pedagogical development in other departments.

We then hosted a four-hour working meeting specific to instituting a pedagogical development seminar in CBEE. The intent was to include key players within CBEE as well as those with valuable experience and perspective from across campus to engage in a conversation around the needs that graduate students have as facilitators. Fifteen participants attended including: faculty members in CBEE who were in charge of graduate student development, taught CBEE Studio courses, the CBEE graduate student coordinator, current CBEE graduate students, the CBEE School Head. Also in attendance were faculty members from the College of Science

who had experience designing and implementing graduate student pedagogical development, department chairs from these units, as well as a member of the graduate school including the Director of Graduate and Postdoctoral Teaching Development in the Graduate School. This group contributed ideas to pedagogical development goals and what pedagogical and professional skills they believed were important for graduate students to acquire while going through the CBEE program.

This workshop provided key community buy-in, and resulted in the following goals for the pedagogical development for graduate students in CBEE. Graduate students would:

1. Develop an identity as part of the CBEE and teaching community
2. Identify and explain different ways of how people learn
3. Identify and explain aspects of teaching practice
4. Explain how to handle the 'logistical' aspects of practice
5. Translate knowledge/skills for teaching into knowledge/skills for research and industry

4.3.2 Seminar Content and Implementation

All incoming CBEE graduate students are required to attend a multi-day pre-Fall orientation to help situate them in the school. One result of the community workshop was a four-hour workshop devoted to pedagogical development for incoming GTAs only. The four-hour workshop was a new addition to the CBEE orientation during the 2016-2017 year and provided sixteen incoming GTAs the opportunity to meet one another, create a GTA community, and indicate to new GTAs that CBEE valued and was dedicated to improving pedagogical practice.

During this workshop incoming GTAs were introduced to what it meant to be a CBEE GTA, an introduction to Studio pedagogy (Koretsky, 2015), metacognition (Tanner, 2012), fixed vs. growth mindset (Dweck, 2007), and learning theory (Handelsman, Miller, &Pfund, 2007). Topics in the workshop were chosen based on topics covered in the University of Colorado Boulder's Learning Assistant Program (Otero, Pollock, & Finkelstein, 2010), which focuses on pedagogical development for undergraduate learning assistants who are in similar roles as GTAs in CBEE. Topics were also chosen to address past issues that GTAs expressed in regards to feeling unprepared to facilitate in Studio and using language of reform based practices but not fully understanding the theory behind them.

New to the 2016-2017 academic year, all incoming graduate students were required to take a 1-credit, 50-minute-per-week professional development seminar each term. The seminar was designed to help graduate students become accustomed to graduate expectations in CBEE (e.g. laboratory rotations, finding an advisor, thesis/dissertation resources, required paperwork) and prepare them for future professional careers (e.g. writing a CV or cover letter). After the community workshop, we worked with the professional development seminar coordinator to determine when time would be devoted to pedagogical development. Originally pedagogical development was not part of the professional development seminar series but the developers of the seminar series were open to providing some guidance on teaching and learning practices for all graduate students, regardless if they were a GTA. We designed and facilitated each pedagogical development session and chose topics that addressed the issues that emerged from the interviewed and observed

GTAs, as well as those that addressed the desired learning goals for the pedagogical development. Table 4.2 provides a description of pedagogical topics covered, the associated learning goals, resources used, and the primary activities implemented.

Table 4.2. Timetable of pedagogical development seminar topics, main resources, and activities

Term	Week	Topic(s)	Goal(s)	Resource(s)	Activities
Pre-Fall Orientation	0	Studio pedagogy Metacognition Fixed vs. growth mindset Learning theory	1, 2, 3, 4, 5	Koretsky, 2015; Tanner, 2012; Dweck, 2007; Handelsman, Miller, & Pfund, 2007	Whole class discussion Read article Small group discussion
Fall	3	Facilitating group work	1, 3, 4	Hauk, Speer, Kung, Tsay, & Hsu, 2013	Instructional video and worksheet
	5	Feedback Self-explanations Mental models	1, 2, 3	Gilbuena et al., 2015; Durkin, 2011; Rankin, 2017; Redish, 1994	Whole class discussion Working with a partner
	7	Imposter syndrome	1	Senior CBEE graduate students Director, Academic Student Success Center	Guest speakers
	9	Professional skills - teaching, learning, and research	1, 5	Feldon et al., 2011; Flaherty, 2016	Individual reflection Small group discussion Whole class discussion Read article
Winter	4	What is knowledge and knowing? (epistemology)	1, 5	Hofer & Pintrich, 1997; Hammer & Elby, 2002	Case studies Small group discussions Whole class discussion
	5	Relevance and creating space for equity and inclusion in engineering	1, 3	Bothwell & McGuire, 2007	Out of class reading Individual reflection in class Whole class discussion Case studies Small group discussions
	7	Stereotype threat	1, 2, 3	Steel & Aronson, 1995; Cohn-Vargas, 2015; Vogt, n.d.; Paige, 2016; Dweck, 2007	Small group discussions Whole class discussion

Table 4.2. Timetable of pedagogical development seminar topics, main resources, and activities (Continued)

Term	Week	Topic(s)	Goal(s)	Resource(s)	Activities
Spring	3	Systems engineering thinking	1, 5	Graduate student doing systems engineering thinking research	Guest speaker Whole class discussion
	5	Systems engineering thinking in action	1, 5	Faculty member who has practice with systems engineering thinking	Guest speaker

For each seminar session, we used Backwards Design (Wiggins & McTighe, 2005) to align our desired goals with topics and activities. Students learn more effectively when they are interacting with others and content (Prince, 2004) so we put emphasis on facilitating activities that applied the topics to a CBEE specific context. Typically each seminar started with a brief introduction to the topic with a reflection question or whole class discussion following. The second half of the seminar focused on the application of the topic to a CBEE specific context. Graduate students were either asked to reflect on or identify situations in which they had encountered topic content or were given case studies that were created from experiences of the facilitator in CBEE. For example, for the seminar topic of "What is knowledge and knowing?" the first half included a short lecture on epistemology models and a whole class discussion around where graduate students typically look for information (e.g. Google, textbooks, other people). The second half of the seminar focused on small group work. Each group was given one case study asking them to reflect on different roles they might encounter: a GTA, a procurement quality engineer, graduate research assistant, or an incoming graduate student from a different discipline (e.g. chemistry). Table 4.3 provides an example of a case study and discussion questions.

Table 4.3. Example of a case study and discussion questions for "What is knowledge and knowing?"

Case: You are a graduate teaching assistant in a studio for Thermodynamics. Each week you get together with the other GTAs and instructor and go over possible solution paths for the studio. This week is a particularly difficult studio and in your meeting, your group comes up with multiple ways to solve the problem. Before studio, you've decided your goal is to try and help students understand different ways to complete the studio. As you are walking around you are noticing that students are really struggling with the concepts and worksheet. Finally, in frustration a student asks you "Just tell me if this is right or wrong, I just want to finish."
Discussion questions: What knowledge is being valued? How would you negotiate this space to move in a productive direction? What are possible solution paths? What questions might you ask to make those involved more reflective for future practice?

The Winter term sessions integrated into a quarter-wide theme on equity and inclusion. A group of interested students and faculty designed and facilitated topics with the course coordinator. Topics for the term included creating space for equity and inclusion in engineering, the danger of a single story/stereotyping, and bridging institutional power structures. During this term, students were put into assigned groups for the entire term. The instructional designers thought it would better serve the graduate students if they worked with the same group members throughout the term to build trust and community. Group formation attended to gender and domestic status to ensure that students felt supported (Oakley, Felder, Brent, & Elhaji, 2004; Finelli & Bergom, 2011).

4.4 Methods and Results

4.4.1 Overall reflections

After each seminar, the first author wrote reflections on the facilitation, the activity, engagement of the graduate students, and improvements for future iterations. These reflections were used to summarize challenges faced in the seminar and areas

that graduate students expressed an interest for future discussion. A summary of the reflections is below.

Student grouping and physical space made a difference in facilitation and engagement. Winter term was the only term in which the graduate students were put into assigned groups of three and there was an observable increase in student engagement with their group and the discussions that followed. While walking around and facilitating discussion, the first author noticed that students who were quiet the term before were actively participating in the group discussion. By the end of term, students who normally did not speak out during whole group discussions also felt comfortable enough to participate. Fall and Winter seminars were in a room with movable desks while Spring term was in a room with stadium seating. With stadium seating, students would often spread out across the rows, which not only removed a sense of community but also impacted how they engaged with group activities.

Not all of the graduate students in any given term were GTAs, so it was important to emphasize how pedagogy and learning theory translate to current or future professional situations. In order to support non-GTAs, we included case studies outside of facilitating learning environments (e.g. scenarios in research labs or industry) and discussions at the end of the session included how topics discussed could be applied in different professional contexts. However, consistently addressing how topics transferred across contexts was sometimes difficult to achieve.

Having the pedagogical development sessions interspersed throughout the professional development seminar did not allow for continuity or for content to build week after week. There was an activation energy associated with each pedagogical

development session because the instructor had to reorient students to the pedagogical topics. Reiterating the importance of the pedagogical topics impacted how the graduate students engaged with the content and discussions. Students who were GTAs would dominate many of the whole class discussions, which indicated that the graduate students who were GTAs needed a venue to talk about practice. Graduate students who were GTAs facilitating Studios picked up on the nuances and constraints of the course and department structure. For example during a discussion on the importance of asking students questions and acknowledging there is not always a right answer, the graduate students stated it was difficult to enforce or approach facilitating in this way because the undergraduate students were assessed based on right or wrong answers. They wanted to know more about how to mitigate the factors out of their control, which we did not have the time to address. Time was a factor in the type and depth of discussions we were able to achieve. Taking time at the beginning of the seminar to explain the importance of the topics took time away from productive discussions.

4.4.2 Survey

We administered a five-section survey to assess the impact of the pedagogical development seminar series at the end of the year. A forced-choice four point Likert scale was used. Topics within the survey included: how the graduate seminar contributed to achieving the pedagogical development goals, how effective different activities were for student learning, the level of knowledge and importance of seminar topics, and demographic information. The survey was piloted with a small group of researchers and graduate students and modified based on feedback. The survey was

administered the last week of Spring term. Participation was voluntary and informed consent was achieved as approved by the OSU IRB. The overall response rate was 76% (n=30). For analysis, we divided responses between graduate students who had reported GTA experience (*n*=20) and those who had no GTA experience (*n*=10). We used an independent *t*-test assuming equal variances to compare differences between groups and a point biserial correlation to determine the effect size of statistically significant differences (Vaske, 2008).

To evaluate the effectiveness of the seminar in helping graduate students to develop pedagogical thinking, we used the needs assessment (NA) model (Borich, 1980). This model provides a way to rank topics in order of priority by comparing *what is* to *what should be* in order to help improve the seminar. For this study, *what is* was the graduate students' level of knowledge on each topic covered, and *what should be* was what was perceived as important to them now and in the future. One limitation to the survey was the graduate students' ability to recall topics and activities of previous terms. We tried to mitigate this limitation as much as possible by asking about general effectiveness of activities. There was also the possibility that graduate students reflected on the whole professional seminar rather than just the pedagogical development sessions.

Table 4.4 summarizes how students believed that the graduate seminar contributed to each pedagogical development goal. On average, graduate students with GTA experience thought that the graduate seminar contributed most to "I can identify connections between teaching skills and industry skills" (*M*=3.10; 1= no contribution to 4= strongly contributed) and contributed the least to "I can explain the

logistical aspects of teaching practice" (M=2.10). On average graduate students with no GTA experience thought that the graduate seminar contributed most to "I can explain the logistical aspects of teaching practice" (M=3.10) and contributed the least to "I see myself as a teacher" (M=2.00).

When comparing the responses for the two groups, students with GTA experiences and students without, there were statistical differences between the statements "I can explain the logistical aspects of teaching practice" (t= 3.83, r_{pb}=0.59, p<0.01), "I can identify connections between teaching skills and industry skills" (t= -2.17, r_{pb}=0.38, p= 0.04), and "I see myself as a teacher" (t= -2.24, r_{pb}=0.39, p= 0.03). The point-biserial correlation effect sizes, r_{pb}, all indicate that the strength of these relationships were "substantial" (Vaske, 2008).

Graduate students with no classroom experience believe the seminar contributed to their ability to explain the logistics of practice, whereas graduate students with GTA experience did not. While it is important to discuss the theory behind practice, GTAs "in the trenches" realize they need competence in logistical aspects of practice such as creating a rubric or using an online management system. This was not a focus of the current pedagogical seminar because we wanted to address topics that all graduate students, regardless if they were a GTA, could use immediately and in the future. Ideally, we need to modify delivery for some specific logistical training, e.g., use one term of the seminar series specifically for this aspect of practice. With the mixed (GTA and non-GTA) cohort, this balance needs to be considered.

Table 4.4 Graduate student perceptions of contribution to seminar goals

*Please indicate how participating in the graduate seminar **contributed** to the following statements:* 1= no contribution to 4= strongly contributed	GTA experience (n=20)	No GTA experience (n=10)
Statement	Mean	Mean
I can identify connections between teaching skills and industry skills	3.10	2.50
I feel like I belong in the school of CBEE	2.90	3.00
I can identify connections between teaching skills and research skills	2.85	2.90
I am aware of multiple components of teaching practice	2.85	2.60
I can identify different ways of how people learn	2.80	3.00
I see myself as a teacher	2.70	2.00
I am confident in my teaching	2.70	2.40
I know best-practices for teaching	2.25	2.60
I can explain the logistical aspects of teaching practice	2.10	3.10

Table 4.5 shows the results to the question regarding graduate students perceptions of how effective each activity in the seminar was to their own learning. The highest average for both groups was "Listening to a guest speaker" (M= 3.10 for GTA experiences, M= 3.30 for no GTA experience) with the least being "Reading articles in class" (M=2.35) for graduate students with GTA experience and "Watching instructional videos" (M= 2.30) for students without GTA experience (1= ineffective to 4= very effective).

Over the course of the year, there were three sessions that were designed around guest speakers: imposter syndrome and both systems engineering thinking sessions. Within each session there was a more passive listening component followed by questions or an activity. The graduate students were asked to watch an instructional video on facilitating group work which showed two examples of mathematics instructors' enacted practice, which was part of a scaffolded activity worksheet (Hauk et al., 2013). The mismatch in content (mathematics vs. chemical engineering) may have impacted perceptions of effectiveness as well as the

engagement of the graduate students in class. Although teaching practices span content, it would be beneficial to create engineering specific instructional videos to reduce cognitive load and increase interest from engineering graduate students. Overall graduate students on average thought interacting with other students was effective for their learning.

Table 4.5. Graduate student perceptions of seminar activities

*Below is a list of activities used during the graduate seminar. Please circle the response that best describes **how effective** each of the following activities are to **your own learning*** 1= ineffective to 4= very effective		
Seminar Activity	GTA experience (n=20, *19) Mean	No GTA experience (n=10) Mean
Listening to a guest speaker	3.10	3.30
Writing reflections on topics in class	2.80	2.50
Working with a partner*	2.79	3.20
Individual reflection in class	2.75	2.70
Whole class discussions*	2.68	2.70
Small group discussions	2.60	3.20
Reading articles outside of class	2.55	2.70
Working through case studies with a small group	2.45	3.00
Watching instructional videos	2.45	2.30
Reading articles in class	2.35	2.60

We used Equation 1 to calculate the weighted rank for both what the graduate students perceived as important now and in the future (Borich, 1980).

$$NA = (Perceived\ importance - perceived\ knowledge) \times average\ perceived\ importance \quad (1)$$

Table 4.6 shows the NA mean ranks for graduate students with and without GTA experience. According to the needs assessment (NA) for both groups, future delivery of the pedagogical development seminar series should focus on addressing facilitating group work, metacognition, and providing feedback.

Table 4.6. Needs assessment (NA) mean ranking for graduate students with and without GTA experience

	GTA experience		No GTA experience	
	NA now (n=20)	NA future (n=20)	NA now (n=10)	NA future (n=10)
Seminar Topic	Mean rank	Mean rank	Mean rank	Mean rank
Facilitating group work	2.01	2.65	1.34	2.47
Metacognition – awareness of your thought process	1.70	2.75	0.62	2.06
Provide Feedback	1.17	2.21	-0.33	1.48
Your own teaching style	0.85	1.77	-1.42	0.32
The diversity of students at your institution	0.77	1.21	-2.48	-0.35
Mental models	0.66	1.29	-0.27	1.15
Fixed vs. growth mindset	0.47	1.56	-0.63	0.35
Stereotype threat	0.45	0.78	-0.90	-0.31
What counts as knowledge and knowing	0.42	-0.26	-1.94	-1.85
Systems engineering thinking	0.32	0.33	-0.65	-0.65
Learning theory	-0.12	0.70	-1.20	0.28
Imposter syndrome	-1.08	-1.67	0.93	-0.83

We also compared the NA differences between graduate students who indicated they had been a GTA and those who had no GTA teaching experience. There was a significant difference between students who do have GTA experience (M= 0.85) and students who do not (M=-1.42) for the NA mean rank for "teaching style" (t= -2.40, r_{pb}= 0.41, p= 0.02); between students who do (M=*0.42*) and students who do not (M=-1.94) for the NA mean rank for "what counts as knowledge and knowing" (t= -2.25, r_{pb}= 0.39, p= 0.03); and between students who do (M=0.77) and students who do not (M= -2.48) for the NA mean rank for "the diversity of students at your institution" (t= -2.56, r_{pb}= 0.44, p = 0.02) regarding importance now. The point-biserial correlation effect sizes suggesting that the strength of these relationships among NA mean ranks was "substantial" (Vaske. 2008). The effect size indicates that graduate students who have some GTA experience believed that "teaching style," "what counts as knowledge and knowing," and "diversity of students" were important topics to talk about and understand in their current situation compared to those

without GTA experience. These topics could be better connected to other aspects of future practice to increase relevance for all.

At the end of the survey the graduate students were given the opportunity to offer any improvements they would like to see. Eleven students responded with suggestions with themes including: bring in guest speakers to talk about academic/industry careers, accommodate for students who are not GTAs, demonstrate exemplary teaching methods including how to "deliver effective lectures," and more interactive activities to mitigate the domination of certain voices. One student recommendation to make activities more interactive was instead of watching an instructional video of practice and discussing in small groups, asking the graduate students to act out common student characteristics and how to facilitate.

4.5 Conclusions

As part of ESTEME@OSU, an institutional change initiative, we conducted initial observations and interviews with graduate teaching assistants (GTAs) in chemical engineering at OSU and determined that there was a need for pedagogical development to help better prepare them to facilitate Studio workshops. As a result we created goals for and embedded topics related to pedagogy into a first-year graduate student professional development seminar. After the pilot pedagogical development seminar series we have the following recommendation:

- Establish goals and buy-in with department community members. Participation from members of other departments and elsewhere in the university can provide useful perspectives and help with buy-in.

- Dedicate an entire term to pedagogical development to allow continuity and allow content to build constructively.
- Assign graduate students into groups for the entire term to create a community and build relationships.
- Focus on the topics of facilitating group work, metacognition, and providing feedback along with helping GTAs better understand their teaching style, epistemology, and the diversity of students at the institution within a pedagogical development seminar.
- With mixed GTA and non-GTA cohorts, provide additional opportunities for the GTAs to develop teaching-specific practical logistical skills.
- Create engineering specific pedagogical instructional videos.

4.6 Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. DUE 1347817. The authors wish to thank the graduate students from the School of Chemical, Biological, and Environmental Engineering at Oregon State University, Devon Quick, Jessica Beck, Anita Hughes, and Jeff Nason. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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5. General Conclusions

This dissertation highlights the important work that GTAs are being asked to do by examining a comparative case study that focuses on both the GTA's enacted teaching practices and epistemological resources and frames in a junior level thermodynamics Studio environment. This research informed the design of a pedagogical development seminar series for engineering GTAs in Studios.

Chapter 2 presented findings about the enactment of three core Studio teaching practices: attending to group dynamics, eliciting student thinking, and providing effective feedback. Both Dean and Jeff showed a high number of instances of directive feedback to students when compared to facilitative feedback. Some students suggested they appreciate the facilitative feedback, while others wanted more directive feedback. On the surface, the emerging ambitious teaching practices enacted by GTAs and students' desire for directive feedback might suggest a less effective implementation of the core Studio teaching practices. However, this understanding does not take into consideration the nuanced negotiation of practice GTAs undertake.

Chapter 3 builds on findings presented in Chapter 2 by investigating the enacted, professed, and reflected epistemological resources and frames of Dean and Jeff in order to understand their enacted practices. The enacted and professed epistemology provided general resources that Dean and Jeff activate. However, through the use of stimulated recall interviews (SRIs), the reflected epistemology provided a more nuanced understanding of how Dean and Jeff make sense of their practice. Dean's identified *frame* was that learning and knowledge creation is a social

process (explanations, peers as resources) that is authored by students who approach problems in multiple ways (there are multiple sources of knowledge and solution paths). Jeff's identified *frame* was that knowledge is transmitted from authority and learning is primarily individual. He was more contradictory in statements than Dean is)

Although Dean and Jeff have different epistemological *frames* as to how learning occurs and who is the author of that learning, they superficially enact similar directive practices. Suggestions for improving practices important within Studios include:

- Provide space for GTAs to be reflective of their practice
- Focus on teaching GTAs how to model metacognitive thinking
- Provide GTAs with opportunities to engage with and understand active learning theories and pedagogies
- Explicitly identify and develop GTA's fostering of student learning within the zone of proximal development

A next step within this research would be to break down the direct explanations that Dean and Jeff provide to students to better understand from a discourse level how GTAs move student thinking forward. Along with this, it would be beneficial to break down the different types of questions each GTA uses and relate that to their epistemological perspective.

Chapter 4 discussed the creation and implementation of a series of pedagogy workshops situated within a professional development seminar for all first year graduate students. For graduate students with GTA experience, the seminar contributed to their understanding of the connections between teaching and industry

skills, while graduate students with no teaching experience felt the seminar contributed most to explaining the logistical aspects of teaching practice. For both groups of graduate students (with or without GTA experience), listening to a guest speaker was, on average, most effective to their learning. This is an interesting finding when coupled with the epistemological frames of Dean and Jeff. For example, the belief that listening, primarily passively to a guest speaker reinforces the *frame* that Jeff enacts, which is that knowledge is transmitted from authority. One way to disrupt this frame is to focus on the topics of facilitating group work, metacognition, and providing feedback, as well as helping GTAs better understand their teaching style, epistemology, and the diversity of students at the institution within a pedagogical development seminar. However, addressing each of these topics take time to discuss in an effective way. Given the constraints of the structure the pedagogy workshops were implemented in, this was not possible with the current pedagogical development workshop model. For this reason we suggest that a sustained, dedicated pedagogical development structure be implemented in order to allow continuity and allow content to build constructively.

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