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An Investigation of the Knowledge, Beliefs, and Practices of Physics Teaching Assistants, with Implications for TA Preparation

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An Investigation of the Knowledge, Beliefs, and Practices of Physics Teaching Assistants, with Implications for TA Preparation

Thesis directed by Prof. Noah Finkelstein

Physics Teaching Assistants (TAs) serve a critical role in supporting student learning in various classroom environments, including discussions and laboratories. As research-based instructional strategies become more widespread in these settings, the TA's role is expanding beyond simply presenting physics content to encompass facilitating student discussion and attending to student reasoning. At the same time, we recognize that these TAs are physics professionals and future faculty, and their teaching experiences in graduate school have the potential for long-term impact on their professional identities. Consequently, there is a need to enhance traditional forms of preparation to support TAs in this expanded role in ways that complement broader professional development opportunities. Enhancing TA preparation requires understanding how TAs make sense of their roles as instructors so that we may identify potential avenues for intervention that support the development of practices that are (1) supportive of curricular goals and (2) consistent with the TAs' overall pedagogical model. The intent of this thesis is to develop a single overarching framework for analyzing how TAs talk about and carry out their roles as instructors. We then apply this framework to a set of interview and video data from multiple semesters, and make claims regarding instances of coordination and dis-coordination between TAs' beliefs and practices. Furthermore, we are able to track changes in beliefs and practices along various time scales. Finally, we return to the issue of TA preparation by identifying features of enhanced professional and pedagogical development, drawn from results of these studies, that could operate within existing institutional structures.

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Chapter 1

Introduction

1.1 Motivation

National calls for science education reform have led to widespread changes to physics instruction at the introductory level [1, 2]. These calls have advocated for preparing students as scientific practitioners through active engagement in authentic practices that mirror those of professional scientists, such as modeling, argumentation, and critical thinking. In response to these calls, decades of research have been conducted toward designing curricular tools that transform and studying their impact on student learning. Early efforts to transform physics instruction began with rethinking the traditional physics lecture to become more student-centered through the design and adoption of new curricula such as *Peer Instruction* [3], *Interactive Lecture Demonstrations* [4], *Just-in-time-Teaching* [5], and *Workshop Physics* [6], which reconceptualize the role of students from being passive recipients of knowledge to being active participants in constructing a robust, connected understanding of physics.

As these instructional strategies have become more widespread, greater attention has been given to how instructors adopt and implement these research-based tools. As we modify courses to promote students' active engagement in the learning process and support the development of scientific reasoning [7] and mastery of conceptual physics content [8], we must attend to how instructors in these environments conceptualize their own roles in supporting these goals [9].

1.2 Teaching Assistants

The predominant model for introductory physics courses in the United States includes several hours of lecture per week, as well as a few hours of smaller classroom sections in which concepts from lecture may be explored in greater detail. These sections can be generally categorized as *discussions* (also known as *recitations*) and *laboratories*. As these sections are smaller and require increased individual contact with students, physics departments commonly employ graduate and/or undergraduate teachers to support student learning and conduct various administrative tasks. These Teaching Assistants (TAs) are commonly graduate students (often recently admitted) who generally receive little formal preparation on teaching. Nevertheless, they are directly responsible for implementing transformed curricula and should therefore be viewed as "partners" in supporting and shaping student learning in these environments [10].

In traditional course models, TA responsibilities commonly involve presenting homework solutions and answering student questions from lecture. In recent years, TA-led sections have become more student-centered through the adoption of research-based curricula such as the *Tutorials in Introductory Physics* [11]. In these settings, there is an increased demand on TAs to: *(1)* engage students in Socratic-style dialogue; *(2)* to attend to students' reasoning; and *(3)* to facilitate student collaboration and discussion [12]. Consequently, there is an increased need for preparation that supports TAs in serving in this expanded role. In many cases, the classroom environment the TA is expected to support may be very different from the one he or she experienced (and continues to experience) as a physics student. In order to accommodate the increased demands on graduate instructors in these environments, the focus of TA preparation must likewise expand to include the discussion of student ideas in addition to the mastery of physics content.

We have chosen to focus on graduate TAs for a number of reasons. First, TAs impact student learning—there is documented correlation between TAs' practices, such as the use of Socratic dialogue, and their students' scores on conceptual post-assessments [13, 14]. Second, as graduate students, TAs are in the process of reconciling their overlapping roles as both teacher and student. They are being exposed to (and expected to participate in) multiple types of educational environments, and the instructional strategies they are expected to support as TAs may be vastly different from those they experienced (and continue to experience) as students. This overlap in student/teacher roles affords a rich opportunity to examine how TAs make sense of teaching and learning at a critical time in their careers.

Finally, we must also recognize that the graduate TAs of today are the faculty of tomorrow, who will be teaching courses, designing and implementing curricula, and working with future graduate and undergraduate students [15]. In the absence of formal pedagogical training, the primary opportunity for TAs to develop and refine teaching beliefs is through their experiences in the classroom and any accompanying weekly preparation sessions. Therefore, the potential for long-term impact on the beliefs of future faculty encourages us to examine how these experiences shape the ways in which TAs talk about and carry out their roles as instructors. Maximizing the positive impact of these experiences requires being attentive to not only the physics content and classroom environment that shape the TAs' roles, but also the methods by which they are prepared to enact these roles each week.

1.3 Calls for studies of TAs

Explicit calls have been made to study and improve TA preparation methods. A report of the 2008 APS Conference on Graduate Education listed among its recommendations for physics departments, to "develop effective TA training programs that pay attention to pedagogy and professional development" [16]. Furthermore, the National Research Council's 2013 Report on Undergraduate Physics Education included among its recommendations for education researchers to "study what makes effective teaching assistants and learning assistants, and provide guidance for those preparing and training them."

Efforts to study TA preparation have been in progress for decades [17], and supplementary coursework has been designed at multiple institutions with the goal of familiarizing graduate students with the breadth of physics education research and its implications for their roles as future faculty [18, 19]. These efforts are complemented by broader programs to support the professional development of graduate students as future faculty (e.g. the national CIRTL network [15] and the Preparing Future Faculty initiative [20]). Despite this increased attention to TA professional development, descriptions of weekly course-specific TA preparation methods and outcomes occupy only a small fraction of published research. Current methods of preparation therefore remain largely undocumented and may consist of informal sets of practices whose relative focus may be subject to broad variation in implementation by course instructors.

Our goals in this thesis are to:

(1) Document a particular approach to preparing TAs to teach using the *Tutorials in Introductory Physics* [11], which draws upon a well-established framework for effective teaching (pedagogical content knowledge), and report on measures of success in focusing instructor attention on student difficulties;

(2) Extend beyond teacher knowledge to examine TAs' beliefs and practices by developing a single overarching coding framework; and

(3) Employ this framework to consider variation and dynamics in how first-semester TAs describe and carry out their roles as instructors.

We will then apply the outcomes of these efforts to make recommendations for a possible model of enhanced TA professional development. In doing so, we identify and seek to address two distinct challenges for weekly preparation of the instructional assistants in the dedicated recitation sessions:

(1) how to effectively address instructors' pedagogical content knowledge, beliefs, and practices; and

(2) how to support all faculty in leading effective preparation sessions, subject to normal constraints (e.g. time, structure, and pedagogical value)

Indeed, the modes of TA preparation presented in Fig. 1.1 require different amounts of resources and departmental buy-in, with higher student-centeredness roughly corresponding to greater resources. For example, preparation that includes reading and discussing student responses requires access to a database of such responses as well as enough time each week to engage in this discussion. Hence we must be mindful of the existing resources and institutional structure in order to suggest enhanced professional development opportunities that operate within local constraints.

Increasing student-centeredness	Form of preparation	Approximate time/week	Necessary resources
	TAs research student difficulties with content	>90 mins.	Structured course with dedicated faculty, syllabus, dept. support
	TAs observe & discuss student difficulties with content	60-90 mins.	Bank of sample student responses
	TAs are told potential difficulties with content	30-60 mins.	List of student difficulties
	TAs review the content	<30 mins.	None
	None	None	None

Figure 1.1: Summary of possible TA preparation models, arranged by increasing student-centeredness.

1.4 Context for Studies

The studies presented in this thesis took place in the reformed introductory physics sequence at the University of Colorado at Boulder (described in [21]). This sequence includes weekly 50-minute recitations using the *Tutorials in Introductory Physics*, an inquiry-based, conceptually-focused curriculum developed by the University of Washington to supplement introductory physics lectures. The tutorials are designed to be completed in small groups with the guidance of a graduate or undergraduate instructor engaging in Socratic-style dialogue. Before attending each week's tutorial, students enrolled in the course receive credit for completing an accompanying "pretest" featuring questions very similar to those in the corresponding tutorial. The pretests are intended to engage students in thinking about the relevant content in advance of the tutorial, and their responses are anonymized and archived for future reference.

In order to address the need for high teacher-to-student ratio in classrooms using tutorials, TAs in these settings are partnered with departmentally-assigned undergraduate Learning Assistants (LAs) to achieve a desirable ratio (approximately 1:14 in tutorials) [22]. In addition to the standard tutorial preparation and teaching experience, first-time LAs enroll in a course on teaching and learning [22, 23]. The TAs do not take part in such a course, although all first-time TAs are required to participate in a pre-semester teaching orientation workshop. This workshop includes a half-day of structured discussion of student learning, research-based instructional strategies, and another day of activities including a mock tutorial and a "microteaching" peer observation workshop.

1.5 Overview of Thesis

In Chapter 2, we provide an overview of the theoretical constructs we will be employing in this thesis and conduct a review of the relevant literature and prior research. We will introduce additional literature in subsequent chapters as we describe how they informed the development of our frameworks for analysis.

Chapter 3 documents our initial studies studies to investigate TAs' awareness of student difficulties with conceptual physics content, a specific component of pedagogical content knowledge (PCK). We then consider a model for developing PCK that builds on existing institutional structure, and document its effectiveness.

The results of this initial study encouraged us to examine TAs' broader perspectives on teaching, as well as how these perspectives compared to in-class practices. Chapter 4 details the subsequent development of a framework for characterizing TAs' beliefs and practices. We call this framework TA-PIVOT (TA's Practices In & Views of Teaching).

In Chapter 5, we apply the TA-PIVOT framework to an expanded set of TAs from the Fall 2011 semester, and track them over the course of the semester to examine dynamics in both stated beliefs and enacted practices. We observe shifts in stated beliefs over the course of the semester, but more significantly, we uncover further instances of inconsistency between TAs' stated beliefs and classroom practices.

Chapter 6 follows up on the findings of the previous three chapters and returns to the question of TA preparation. We propose a number of recommendations and heuristics for TA preparation that incorporate methods introduced during these studies, while building upon existing models for the development of professional practice. We conclude with a summary of the scope of this thesis and future directions for continuing research.

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Chapter 2

Literature Review & Theoretical Perspective

2.1 Introduction

Our approach to Teaching Assistant professional development considers not only the forms of knowledge that are useful for teachers of physics, but also their beliefs about the nature of teaching. However, these two constructs alone ignore a critical piece of the puzzle: how instructors enact their roles as teachers in a classroom setting. In this chapter we summarize our theoretical approach to each of these components and document prior investigations that we draw upon in our work. This chapter serves as a foundation and starting point for motivating our research; we will continue to introduce more specific theoretical constructs and prior studies in the coming chapters as we describe the development of our analytic framework.

2.2 Conceptual framework

2.2.1 Pedagogical content knowledge

In order to describe the type of specialized knowledge we expect instructors to develop and subsequently employ in the classroom, we draw upon the extensive literature of pedagogical content knowledge (PCK). As originally defined by Shulman, PCK is the specialized knowledge possessed by teachers that combines knowledge of content with knowledge of pedagogy [1]. In elaborating on teacher knowledge, Grossman et al. argue that the type of subject matter knowledge necessary for teaching a subject is fundamentally distinct from the subject matter knowledge possessed by an expert in that subject [2]. Magnusson *et al.* go further in outlining the finer-grained structure of PCK as well as a model for its development [3]. Etkina also describes an multi-year teacher preparation program that includes the development of PCK as an explicit focus [4]. Others have developed instruments for assessing components of PCK [5] and demonstrated that teachers' level of PCK is correlated with the degree to which their classroom is reform-oriented [6].

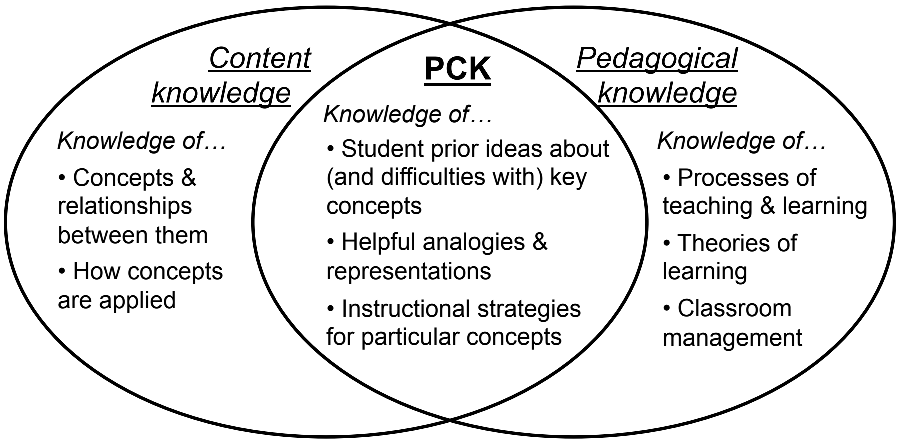

Figure 2.1: Pedagogical content knowledge as the intersection of content and pedagogical knowledge (adapted from Etkina [4]). Bulleted items are exemplary and not comprehensive.

If a goal of traditional graduate or undergraduate physics education is to develop content knowledge, we argue that the complementary role of physics teaching experience should be to develop PCK. That is, physics instructors should not only develop a robust understanding of physics content, but also refine strategies to teach that same content in ways that build upon students' prior knowledge. It should be noted that we do not view content knowledge and PCK as isolated knowledge domains; research has shown that teaching in transformed environments improves traditional content knowledge [7], and recently published findings report that graduate students with teaching experience demonstrate greater improvement in scientific research skills than those without [8].

2.2.2 Pedagogical beliefs

The ways in which teachers think about what goes on in the classroom and how they conceptualize their roles in working with students are the subjects of broad attention in education research, spanning pre-service K-12 teachers to university faculty [9–15]. Numerous studies have investigated how teachers develop an understanding of the nature of teaching, as well as how such an understanding relates to the instructional practices. As noted by others [9, 10], the overall coherence of these studies is inhibited by a general lack of agreement and consistent use of terminology such as beliefs, conceptions, perspectives, attitudes, and values (just to name a few).

Efforts to synthesize prior studies regarding teacher beliefs have yielded useful sets of assumptions upon which subsequent studies may be based [9, 11]. In particular, “beliefs” are generally understood to be tacitly held [12, 13], have some connective structure [14], and appear critical to how people define, interpret, and make decisions regarding their behaviors in social settings [11, 15]. [16] In this study, we have chosen to employ the construct of beliefs, and we use it to mean tacit, personally held values and assumptions that shape how teachers interpret classroom situations. In other words, beliefs serve as a lens through which TAs view classroom situations.

In considering instructors’ beliefs, we cannot ignore their contextual nature. Just as student learning of physics must be considered within nested levels of particular contexts [17, 18], we must also consider how beliefs are supported, constrained, and shaped by local context. Hoyles [19] describes all beliefs as being situated as a result of being constructed within particular contexts, and Pajares [9] similarly emphasizes the context-specific nature of beliefs. This context dependence will become particularly important in comparing beliefs and practices or considering the “transfer” of beliefs between classroom environments, since different contextual factors may tend to elicit different beliefs [20].

2.2.3 Instructional practices

A natural complement to how teachers think about and describe their own teaching is how they enact their roles as teachers in the classroom. Numerous studies have indicated that instructors' beliefs about teaching influence their classroom practices [21, 22], although the exact relationship between beliefs and practices is complex and not a "one-to-one" mapping [23]. Thus we purposefully avoid ascribing "enacted belief" labels to classroom practices, as the practitioner and researcher may not agree on the belief reflected by a particular practice.

Furthermore, the relationship between beliefs and practices is mediated by local constraints, and such constraints may weaken the coordination between them [21]. One model for this relationship, illustrated in Fig. 2.2, is that instructors' beliefs and practices must be considered as being situated within local context, which mediates the relationship between them. Prior studies indicate that faculty operating within similar instructional settings negotiate situational constraints differently, and their ability to do so is reflective of the sophistication of their overall teaching model [24].

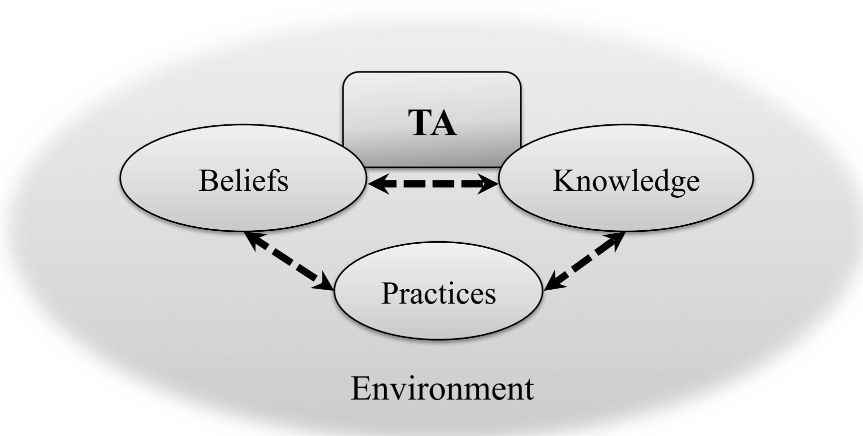

Figure 2.2: Beliefs and practices as mediated by environmental constraints.

It is tempting to use teachers' classroom practices as a proxy for their beliefs, and vice versa. However, in the words of Kane *et al.* [25], considering only teachers' talk amounts to "telling half the story" and limits our ability to investigate the nature and contextual dependence of instructors' pedagogical beliefs. Instead we must consider both how teachers describe their views of teaching and enact practices in educational settings. In other words, talking to TAs and asking them to describe what matters to them in enacting their role as teachers allows us as researchers to more completely understand the decision-making process that TAs undergo in the classroom.

Nespor concluded that beliefs are far more influential than knowledge in discerning how individuals frame problems and organize tasks and are stronger predictors of behavior [12]. In this thesis we are not investigating a causal link between the two (i.e. do particular beliefs drive particular practices and vice versa), but rather the nature of coordination between beliefs and practices. In doing so, we build upon the approach of recent studies of math and physics TAs that employ a combination of video observations and interviews to provide a more complete picture of their beliefs and practices [23, 26].

2.3 Prior Research

2.3.1 Development of instruments

Extensive research has been conducted toward examining the beliefs and practices of pre- and in-service K12 teachers and university faculty. To this end, numerous instruments have been designed for documenting instructors' use of particular practices, for example the Reformed Teaching Observation Protocol (RTOP) [27] and Teaching Dimensions Observation Protocol (TDOP) [28]. Likewise, frameworks exist to characterize instructors' views on the nature of teaching, usually through the use of interviews and surveys [29–32]. Previous research on university academics' teaching has tended to focus on either interview or observational data alone, one as a proxy for the other. In particular, there is not an existing framework that spans the contexts of beliefs and practices in order to examine similar constructs within each domain.

Our interest in outlining a framework for bridging beliefs and practices is built upon a number of objectives. First, such a framework would afford greater insight into the nature of beliefs and practices as situated within particular educational environments (Fig. 2.2). Second, it would allow us to uncover and examine instances of consistency and inconsistency between beliefs and practices, and allow us to consider the factors contributing to these instances. Additionally, examining the nature of coordination between beliefs and practices allows us to assess the bounds of proxy; that is, we may be able to tell *to what extent* and *under what conditions* measured beliefs may be substituted for practices. As noted earlier, a particular tendency in the literature is to ascribe beliefs to particular practices and vice versa; a greater understanding of coordination would in turn streamline future data collection in these settings by providing an empirical basis for the substitution of survey or interview responses for direct observation of practices.

On the more applied side, the creation of such a framework is a critical step in documenting and transforming TA preparation and professional development. There is a recognized need for investigating the effectiveness of existing preparation methods in helping TAs develop and refine productive pedagogical beliefs and practices [33]. Previous research has demonstrated that key factors in the ability of physics faculty to persist in using research-based course transformations include: *a)* an awareness of course transformations; *b)* a belief in the effectiveness of course transformations; and *c)* the awareness of barriers or constraints to the implementation of course transformations [34]. Furthermore, instructors' ability to negotiate such barriers appears to be grounded in their broader teaching perspective [24].

Our separation of the domains of beliefs and practices is analogous to how Argyris and Schön distinguish between their constructs of "theories of action" and "theories-in-use" [35]. They describe the two types of theories in this manner:

> When someone is asked how he would behave under certain circumstances, the answer he usually gives is his espoused theory of action for that situation. This is the theory of action to which he gives allegiance, and which, upon request, he communicates to others. However the theory that actually governs his actions is his theory-in-use, which may or may not be compatible with his espoused theory; furthermore, the individual may or may not be aware of incompatibility of the two theories. (Argyris & Schön, 1974)

In other words, interview and videotape data provide complementary perspectives of how TAs conceptualize teaching and learning physics, which are not necessarily coordinated with one another.

This may be especially true for novice teachers, like graduate TAs, who are yet in the process of developing conceptions of teaching and learning.

2.3.2 Teaching Assistants

A growing body of research has been dedicated to considering how Teaching Assistants engage students in the classroom. In the physical sciences, studies have considered TAs' practices in inquiry-based classroom environments [37], with an eye toward designing effective TA training programs. These researchers make the argument that expecting TAs to develop sophisticated teaching capabilities in the absence of adequate support amounts to "growing a garden without water" [38]. Other work has also examined TAs' PCK in chemistry lab settings [39]. In physics, Goertzen *et al.* examined how TAs frame tutorial activities in different ways [40]. Furthermore, the extent to which TAs agree with (or "buy in") to the goals and structure of transformed curricula is a necessary (but not sufficient) factor in their ability to effectively implement those curricula [41].

Studies of TAs have started to specifically consider the relationship between beliefs and practices. Notably, Speer examined the connection between a TA's beliefs and practices regarding problem-solving through a structured interview in which a math TA talked through a recorded episode of his own teaching. Speer identified four broad categories for teacher beliefs: *a)* beliefs about students; *b)* beliefs about teaching; *c)* beliefs about learning; and *d)* beliefs about mathematics. Furthermore, she found that particular collections of beliefs affect moment-to-moment teaching decisions such as when to ask questions [26]. Goertzen also found that similar types of practices used by TAs may be supported by different beliefs [23]. We build upon these approaches by likewise considering both beliefs and practices, but extend the focus to developing a common framework for analysis across these domains.

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Chapter 3

Tracking TA Awareness of Student Difficulties with Physics Content

3.1 Introduction

Our initial effort to examine TA preparation focused on knowledge of student difficulties as a specific component of pedagogical content knowledge. As discussed in the previous chapter, knowledge of student misconceptions is part of Shulman's original construct of PCK [1]. We chose to focus on student difficulties in part to couple to the curricular approach of the *Tutorials in Introductory Physics* [2], which are designed to address commonly identified misconceptions with physics content, but also utilize existing institutional structure for preparation.

The research questions driving this study are:

(1) How does TA awareness of student difficulties shift over the course of a week of teaching?

(2) What is the impact of our preparation on this awareness?

3.2 Study

3.2.1 Setting

A few days before they teach a tutorial, the TAs and LAs all attend a weekly preparation session facilitated by one of the course instructors (a faculty member). The sessions typically last between 60 and 90 minutes depending on the length of the tutorial, and take place in the same classroom space as the recitations. Thus the sessions are designed to mirror the feel of an actual recitation, with TAs and LAs in the position of students, in order to reinforce the goal of thinking about and discussing student reasoning. During the meeting, the facilitator ensures mixed seating of TAs and LAs in order to stimulate discussion and ensure a range of experience levels within each group.

Following the model of the University of Washington [6], weekly tutorial preparation sessions at CU are intended to guide TAs and LAs to think about and discuss potential student difficulties in addition to physics content. The sessions are structured around three primary components, in which TAs and LAs: *(1)* complete the weekly tutorial pretest individually; *(2)* view sample responses to the pretest drawn from archived student work, and discuss their observations of student reasoning first within small groups and then with the large group; and *(3)* complete the tutorial in small groups while the faculty facilitator discusses possible student responses and instructional strategies with each group.

By emphasizing both physics content and pedagogy, this approach to preparation addresses the two primary knowledge bases that constitute PCK. Under this model, instructors are developing PCK not by evaluating the correctness of student responses, but rather by identifying what responses say about students' prior knowledge and how they might work with and build upon such knowledge in the classroom. The specific attention to actual student ideas is therefore intended to guide instructors in drawing the distinctions and relations between content and pedagogical knowledge that will inform instructional strategies in the classroom.

While the general procedure for tutorial preparation has remained fairly consistent from semester to semester, we observe some variation among faculty instructors in the relative emphasis they place on understanding content versus developing pedagogical approaches. This relative emphasis is exhibited in the amount of time spent on various components of preparation as well as the framing of these components, which may depend on the faculty instructor's experience as a facilitator and the instructor's familiarity with physics education research. This variation prompted us to investigate the impact of weekly preparation on the TAs' and LAs' awareness of student difficulties, in order to use the results to make weekly preparation more consistent and effective.

3.3 Pilot study

A single-week pilot study was conducted during the Fall 2008 semester of Physics 1120, the calculus-based introductory electromagnetism course. The study was conducted during the week of the "Faraday's Law and applications" tutorial. Thirteen instructors (7 TAs, 6 LAs) taught in recitations this semester, and each participated in the study. Immediately following their preparation session, the TAs and LAs for this course were asked to provide the top three common student misconceptions that they expected to face in their next class. After teaching, they were then asked to report the three most common student misconceptions that they observed on the day of teaching.

We chose to categorize responses by the page of the tutorial on which they appeared. Fig. 3.1 shows the frequency of each response category among all 13 recitation instructors, as well as the central idea of that page. The first two pages of "Faraday's Law and applications" are conceptual with no hands-on component, while the remaining four pages involve the construction of a simple galvanometer and motor. The "Other" category includes general concepts (such as the right hand rule) that apply to multiple pages, as well as non-conceptual difficulties with materials.

A few prominent features of this graph give us some idea about how the instructors' awareness of the ideas presented in the tutorial. For instance, every instructor predicted and observed the student difficulty concerning induced *emf* in the absence of a conducting loop (C1). However, the instructors underestimated a common student difficulty involving a comparison of resistance and induced *emf* for different loops in identically changing magnetic fields (C2). The notable aspect of this particular difficulty is that it is the only one of the five difficulties addressed by the pretest, and it is repeated in an identical form in the tutorial itself. According to the Instructor's Guide, "very few students correctly relate the current, resistance, and emf of these three loops" [6].

Our interpretation of this outcome is that while TAs and LAs may be completing the pretests correctly during the preparation session, course instructors may not be framing the pretests as addressing common student difficulties. Indeed, post-semester interviews indicated that many TAs/LAs view the pretest as simply a "warm-up" for students (and themselves) rather than a tool

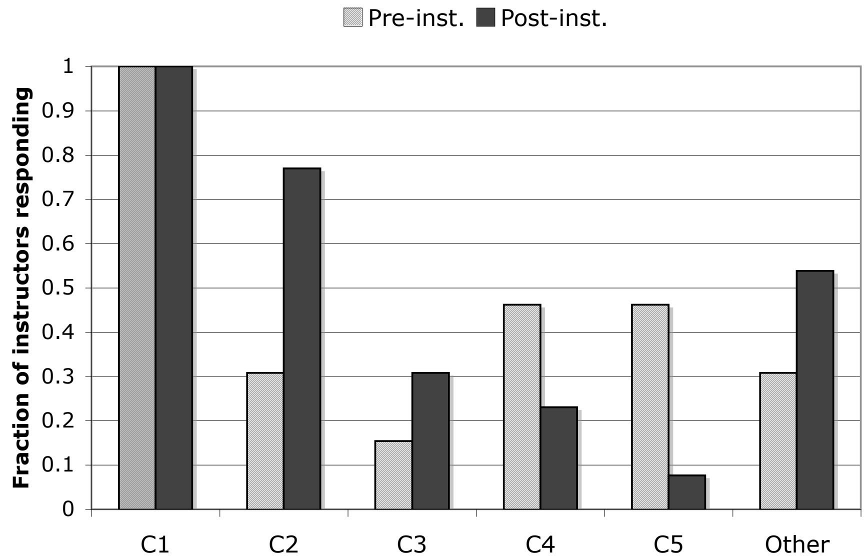


Figure 3.1: Predicted and observed student difficulties for the "Faraday's Law and applications" tutorial. *(N=13)* C1: Induced *emf* without conductor/current; C2: Comparing resistance & emf between loops; C3: Direction of galvanometer deflection; C4: Purpose of half-stripped insulation in motor; C5: Rotation of motor coil

to elicit student ideas. With this result in mind, a multi-week follow-up study was designed for the following semester.

3.3.1 Methods

Study A took place over four weeks (10th-13th) of Physics 1110, the calculus-based introductory mechanics course at CU, and Study B ran for 13 weeks in a subsequent semester of the same course. In each of these studies, we administered surveys regarding expected student difficulties at three points during the week: once before the weekly preparation session; again after preparation but before teaching; and once more after the instructors had finished teaching (Fig. 3.2). The wording of each prompt is given in Table 3.1. The participants completed each survey outside the preparation session using an online form. In the context of this study, I do not distinguish between graduate and undergraduate instructors, as significant differences did not emerge between their responses. I will refer to TAs and LAs collectively as Instructional Assistants (IAs).

The surveys asked specifically for the *three most common* student difficulties. Three was chosen as an achievable number in an effort to elicit more IA ideas, given that prior studies, which did not ask for a specific number, tended to generate fewer responses. We chose to ask for *most common* difficulties as opposed to *most important* as this allows IAs to make a comparison without introducing confusion on how to judge relative importance. In doing so we are relying on the fact that the *Tutorials* are explicitly designed to address research-based student difficulties and conceptions, which have been externally validated as important.

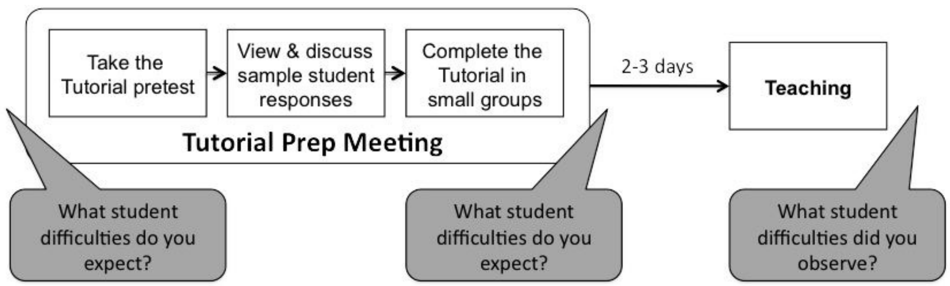


Figure 3.2: Weekly structure of Study A (4 weeks).

Participation in Study A was not mandatory; over the course of the four weeks, 9 IAs (out of 13 assigned to the course) participated frequently enough (at least a 75% overall response rate) that their responses could be satisfactorily followed from week to week. The 9 participants were demographically representative of the broader population. Participants were never given feedback about their responses. It was expected that the IAs would not view the tutorial before the preparation session, and hence the pre-preparation survey asked for student difficulties on the *topic* of the tutorial rather than the tutorial itself. I coded the IAs' responses into categories in order to describe shifts in the types of student difficulties they identified. The categories were formed by reviewing the types of concepts and reasoning used in each section of the tutorial itself, and by consulting the Instructor's Guide [6] where available.

Based on preliminary results for Study A [7], we designed a subsequent semester-long Study B that modified the standard preparation to include the three prompts as an expected part of practice (Fig. 3.3). Additionally, we increased the overall focus on the tutorial pretest by asking

Pre-prep	The topic of the next tutorial will be [TOPIC]. In the blanks below, please describe the three most common student difficulties that you associate with this topic. (That is, what do you think students usually have the most trouble with when learning this topic?) Please be as specific as you can.
Pre-teaching	The topic of the next tutorial will be [TOPIC]. In the blanks below, please describe the three most common student difficulties you expect to face on the day of the tutorial. (That is, what specifically do you expect your students to have the most trouble understanding?)
Post-teaching	You are done teaching [TOPIC]. In the blanks below, please describe the three most common student difficulties that you observed while teaching. (That is, what specifically did your students have the most trouble understanding?)

Table 3.1: Wording of survey prompts.

IAs to complete the pretest online *before* attending the preparation session. During the meeting, IAs first completed the tutorial in small groups, and then viewed student responses to the pretest before ending the meeting with a full-group discussion of predicted student difficulties and how to address them. This study ran for thirteen weeks (one for each tutorial) and averaged an 86% participation rate (more than 13 IAs out of 16 total) across all surveys.

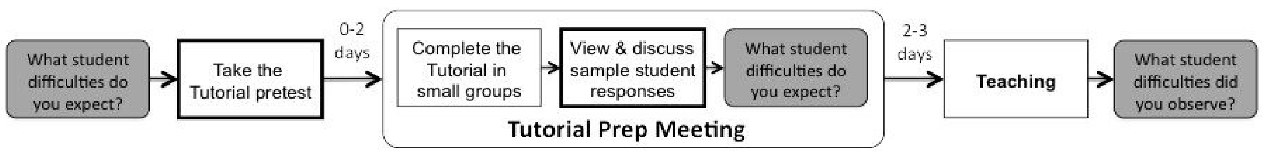
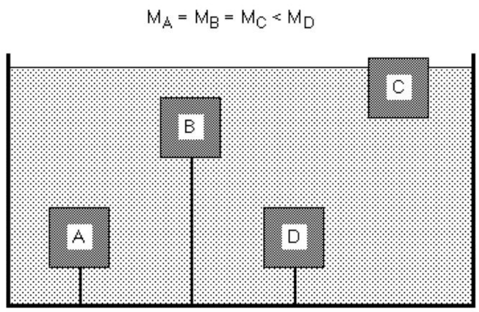


Figure 3.3: Weekly structure of Study B (13 weeks). Note that the prompts from Study A have been incorporated into preparation and the ordering of preparation components has been changed.

In order to further emphasize the anticipation of student difficulties as a valued component of preparation, we added follow-up questions to the pretest later in the semester. These questions asked IAs to describe a possible incorrect response after they had given their own correct response. As an example, Fig. 3.4 shows a pretest question from the "Buoyancy" tutorial along with a follow-up question asking for a possible incorrect response and explanation along with an appropriate instructional approach.



1. Is the buoyant force on block A *greater than, less than, or equal to* the buoyant force on block B? Explain your reasoning.

2. Choose a response to the above question that you believe to be incorrect. Briefly describe why a student might choose that response, and what you might do to help that student.

Figure 3.4: Tutorial pretest question from the “Buoyancy” pretest with added follow-up question.

3.4 Results

We previously examined results for a single week of this study and reported indications that *(1)* weekly preparation was successful at drawing IA attention to student difficulties addressed by the tutorial, and *(2)* while the pretests did align with common student difficulties reported by instructors, the presence of several “underestimated” difficulties suggested that instructors may be missing common student difficulties that appeared on the pretest [7]. Here we examine the validity of these claims across the expanded studies.

3.4.1 Focusing instructor attention

Each week, IAs must decide exactly which aspects of a particular physics topic to focus on in the classroom. We use the first survey each week to gauge IAs’ inital ideas about student difficulties with the weekly topic—in other words, the student difficulties the IAs consider particularly prevalent and hence would likely choose to address in the absence of any provided instructional materials or guidance. In Table 3.2 I provide several examples of instructors’ ideas about student difficulties both before and after preparation. We note how ideas before preparation tend to be broad or focused on calculation and mathematical formalism, but become more attentive to specific conceptual difficulties and more closely aligned with the tutorial content following preparation.

	Pre-preparation	*Post-preparation*
LA 1, Work and changes in KE (Week 7)	"Understanding that kinetic energy is not a state function unlike potential energy"	"Remembering that $F_{net} \times d_{net}$ cannot be used to calculate W_{net}"
TA 1, Cons. of angular momentum (Week 12)	"Calculation of moment of inertia"	"L is related to [an] observation point"
LA 2, Cons. of angular momentum (Week 12)	"Students might have trouble with concepts from angular momentum"	"...that [linear] momentum is converted [into angular momentum] or momentum 'splits up' "
TA 2, Simple Harmonic Motion (Week 13)	"They have a difficult time [doing] the calculus for the sinusoidal function"	"They get confused about how kinetic energy and the potential energy transfer to each other in SHM"
TA 2, Buoyancy (Week 14)	"How to calculate buoyant force"	"[Students] may think the buoyant force is related to depth"
TA 3, Buoyancy (Week 14)	"Buoyancy of irregular objects"	"Heavier objects do not necessarily have a smaller buoyant force"

Table 3.2: Sample IA responses before and after preparation.

We use the aforementioned categorization of responses to track shifts in IA awareness of student difficulties during a complete week of preparation and teaching. As an example, Fig. 3.5 shows how IAs' responses shift during the week of the tutorial "Conservation of angular momentum." Categories marked with an asterisk are addressed by the tutorial pretest, suggesting that the tutorial designers consider them particularly prevalent or important. Here, we note that each of the "underestimated" student difficulties (C1, C4, and C6, which were observed more often than they were predicted) were addressed by the tutorial pretest.

In order to further compare the IAs' focus with that of the Tutorial designers, we divide the categories of student difficulties into three groups: *"On pretest"*, meaning the category was addressed by both the tutorial and the pretest; *"Not on pretest"*, meaning the category was addressed by the tutorial but not the pretest; and *"Other"*, meaning the category was addressed by neither the tutorial nor the pretest. In Fig. 3.6 we have collapsed data from all weeks of the two studies (17 weeks total) in order to demonstrate overall trends.

First, we note that the fraction of responses categorized as "Other" drops sharply follow-

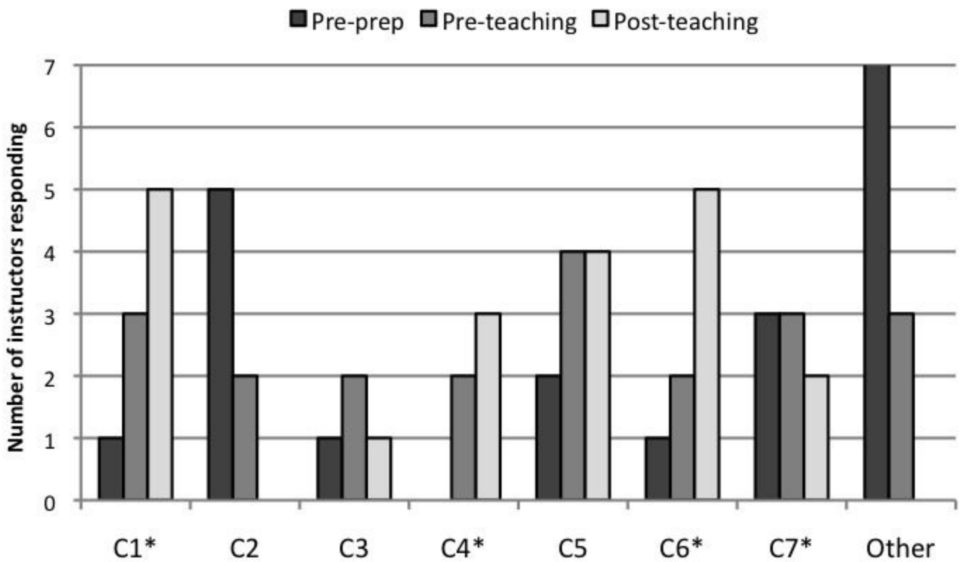


Figure 3.5: Predicted ("Pre-prep" and "Pre-teaching") and observed ("Post-teaching") student difficulties for the "Conservation of angular momentum" tutorial (Week 7). Only instructors who responded to all three prompts are included (N=7). C1: Application of L to student-wheel system; C2: Direction of L vector; C3: Conservation of L as a vector; C4: C.O.M. motion in collision; C5: Distinguishing angular/linear momentum; C6: Non-rotating object can have L; C7: L defined with respect to a point. For further discussion, see Spike and Finkelstein [7].

ing preparation (and again after teaching, suggesting that IAs continue to learn about student difficulties). Furthermore, following preparation, a slightly higher fraction of predicted difficulties appear on the tutorial pretest than do not, which suggests to us that our preparation model (which includes an explicit focus on the pretest) increases IA attention to common student difficulties. We take both of these observations as evidence that this preparation method succeeds at focusing IA attention on student difficulties addressed by the pretest. In fact, there may be some evidence of over-focusing on the pretest, since after preparation a greater fraction of the listed student difficulties appear on the pretest than do not, yet the opposite is true after teaching. This result suggests that more could be done as part of preparation to connect the pretests back to the tutorial itself, such as discussing how students with particular pretest responses might respond to similar questions on the tutorial.

Each tutorial addresses a subset of student difficulties within a particular topic, such as

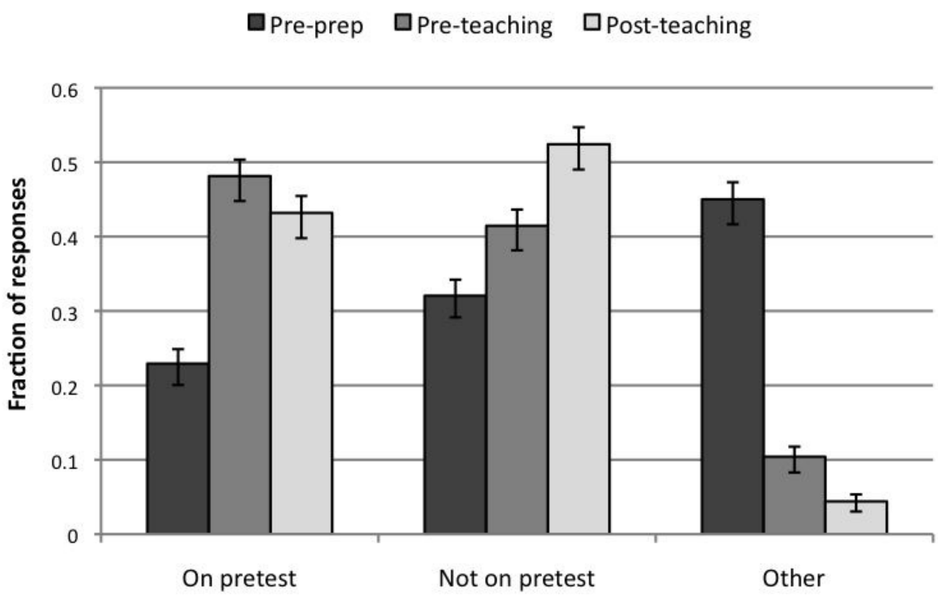


Figure 3.6: Predicted and observed student difficulties for all weeks, reported as a fraction of all responses for that survey (N=471 for pre-prep, N=509 for pre-teaching, N=477 for post-teaching). Error bars represent the standard error on the proportion.

"Forces" or "Conservation of momentum". It can be challenging for IAs to accurately predict student difficulties without seeing the tutorial first, as evidenced by the relatively high "Other" fraction before preparation. This finding is not meant to suggest that the IAs' initial predictions are entirely unfounded, but rather that they may be outside the scope of the tutorial. For instance, during week 13 ("Simple Harmonic Motion"), over half the pre-preparation predicted difficulties were categorized as "Other," including predicted difficulties regarding angular speed, phase, and the small angle approximation. (None of these concepts are addressed by this particular tutorial.) Following preparation, these predictions are refined into ideas about student thinking that are more immediately useful to teaching that tutorial. In the end, these preparation meetings are focusing IAs attention on the content that is contained on the Tutorial itself, rather than the broader topic.

3.4.2 Implementation & institutional framing

This study was designed to leverage existing resources and structures in order to promote departmental buy-in and sustained use. In advance of implementing any changes to weekly preparation, we contacted our department's Associate Chair for Undergraduate Studies (a faculty member in charge of assigning and managing both TAs and professors). In his opinion, this weekly preparation model fits with the department's framing that being attentive to student difficulties is part of the IAs' hired duties. Furthermore, he appreciated that this model promotes shared responsibility for preparation without adding significantly to IA or facilitator time, and also allowed a mechanism for monitoring IA participation.

Collecting individual IA pretest responses in advance of the weekly meeting also allows insight into the conceptual understanding of graduate students and advanced undergraduates. It was previously difficult to collect individual pretest responses because IAs tended to correct and assist one another due to the collaborative nature of the session. In reviewing the IAs' individual pretest responses, we found that both TAs and LAs had difficulties with some tutorial pretest questions—which is consistent with prior findings that neither group begins the semester with a complete mastery of introductory physics [5] This finding justifies our decision to hold the discussion of student ideas *after* completing the tutorial, when IAs have a stronger conceptual foundation on which to base instructional strategies.

In addition to preparing IAs, we view these meetings as an opportunity for the preparation and pedagogical development of faculty. This approach to preparing IAs engages and supports the faculty facilitators' understanding of and approach to the preparation sessions—emphasizing the development of IAs pedagogical knowledge in addition to content knowledge. In this way, all faculty become more closely involved with the outcomes of physics education research and the implementation of curricular reforms. The use of full-group discussion during the sessions is intended to engage faculty not only with students' ideas, but their IAs' ideas as well. Further studies in this vein will involve targeted interviews to better understand how faculty perceive and implement various aspects of this preparation model.

Lastly, we view this study as a productive example of coupling between research and instructional practice. This study was originally intended to evaluate the effectiveness of how particular aspects of curricular reforms are implemented, and is now gradually becoming embedded as formative assessment within that implementation. Going forward, we will examine how and in what ways transformed preparation—like transformed instruction—is sustainable within the confines of existing institutional structures and leads to sustained practices on the part of instructors.

3.5 Discussion and Conclusions

At first glance, these findings appear to confirm the obvious—instructors become more familiar with ideas addressed by the tutorial as a result of preparation—but we argue that the importance of this study should not be understated. First, we believe that through explicit focus on student difficulties, we are also preparing IAs to think in particular ways about the tutorial—specifically to anticipate how students might respond to each question—that they otherwise might not in the absence of preparation. Second, by focusing IA attention on student difficulties addressed by the tutorial, we are simultaneously reducing their attention to ancillary issues that are not addressed (as evidenced by the decreasing fraction of "Other" responses)—allowing them to focus more effectively on ones that are addressed.

We can take a page from our studies of undergraduate student learning of physics to know that we should not expect physics instructors to learn about student ideas simply "by telling." The model of preparation we describe is intended to go a step further by engaging IAs in learning student difficulties through the process of reading and discussing actual student responses. Although this generally requires a greater time commitment than traditional preparation methods, it allows instructors to engage with and understand student thinking in the same way that we expect our students to learn physics. The opportunity for the examination and discussion of student thinking afforded by these preparation methods is likely critical to their effectiveness. Others have recognized the pedagogical value of this approach and integrated it into teacher preparation curricula [8]. Furthermore, it has been demonstrated that instructors who have an awareness of common student misconceptions have higher student learning gains than those who do not [9].

Now that we are aware of our ability to focus IA attention on student difficulties, subsequent studies may investigate how the subtle parameters of variation (such as the faculty facilitator's framing) may either support or inhibit the IAs' discussion of student ideas during preparation (and in turn, the development of specialized knowledge necessary for effective teaching). We offer this study as one example of how forms of evaluation and formative assessment can become embedded in—and subsequently transform—traditional forms of preparation, and we will return to discuss features of this model in Chapter 6.

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Chapter 4

Development of a Framework for Characterizing TA Beliefs and Practices

4.1 Introduction

The previous chapter the development of a component of PCK. However, developing knowledge for teaching is only part of the story, and ignores the broader conceptions of teaching. In order to more completely understand how the development of this component of PCK impacts the IAs' instructional practices, we must observe these instructors as they apply this attention on student difficulties to their own teaching. We call this framework TA-PIVOT (Teaching Assistants' Practices In & Views Of Teaching).

4.2 Study

4.2.1 Methods

The development of the TA-PIVOT framework originally began with preliminary end-of-semester written surveys designed to elicit TAs' definitions of teaching, as well as their self-reported reflections on how their ideas about teaching had changed during the semester. Responses to these surveys tended to be brief, but nonetheless provided emergent themes that informed the design of a subsequent interview protocol.

Drawing from other interview approaches [1, 2], we then designed an interview protocol that would allow TAs to elaborate on their responses and, in particular, describe specific teaching instances in greater detail. These interviews (approved by the Internal Review Board and with participant consent) were approximately 40 minutes in length and semi-structured in that the interviewer could ask to clarify or follow up on specific points at his discretion. The protocol also included open-ended questions to identify broad themes (e.g. "What is teaching, to you?"), as well as opportunities to reflect on specific classroom events. The complete interview protocol is listed in Appendix A.

In parallel to the interviews, we collected classroom recordings using fixed cameras trained on tables of about 4 students, in a manner similar to the fixed-camera observational studies conducted by the University of Maryland [3]. Students and TAs were informed beforehand when recordings were taking place, and consent was obtained in accordance with campus human subjects protocols (Appendix B). Researchers were not present in the room during recording. We then identified and extracted video clips in which the TA was present at the table (which we will refer to as "episodes"), which were then coded as described below.

4.2.2 Data

Our data inventory included 8 TAs who were both interviewed and videotaped, as well as an additional 18 TAs who were interviewed but never videotaped. All of the videotaped TAs served in tutorial sections of Physics 1110. We also conducted limited interviews and videorecordings of TAs in traditional laboratory environments of algebra-based introductory courses for comparative purposes and in order to test the reliability of the framework across classroom settings. In Chapter 5, we will add an additional 5 TAs to this data set, for a total of 13 interviewed & videotaped TAs.

To supplement our interview and video data and provide contextual information for our observations, we collected additional data including: interviews and videotape of undergraduate Learning Assistants who worked alongside TAs in tutorial settings [4], early surveys that informed the development of the interview protocol, and field notes from TA preparation sessions.

4.2.3 Analysis

Even before collecting video data, we began by coding interview transcripts to identify recurring themes and patterns of speech. Our unit of analysis was individual phrases and sentences rather than complete answers to questions, as we found that TAs jumped around to various themes between questions, and any given response could be coded The emergent themes that resulted from this open coding are given in Table 4.1.

Table 4.1: Emergent codes from interview data.

Code	Definition	Example
Explaining	TA provides the answer or explanation of answer	I would... work through it really quickly on the board, and say, "If you have questions about how to do this, this is the way to do it."
Pace setting	TA decides where to start & at what speed	I prefer to start from scratch. So let's say they're at some stage. If I continue from this stage, I actually won't know whether they're clear on the previous stages. OK, so I'll go from scratch, but maybe I'll go slightly fast.
Demonstration	TA models a process or way of thinking	When you said, "Well, I'll <u>do</u> this, I'll show you how <u>I</u> do this," they would be a lot more, "Oh, hey, show me that," than some of the others were.
Authority	TA sets rules, has the final say	...it's a very different dynamic now where I sort of have to be the authority figure as opposed to before where the professor was still ultimate authority.
Encouragement/ motivation	Providing encouragement to students	I think also being encouraging of the students is good... They want to learn, so it's good to keep encouraging them, stay positive, and have them learn stuff.
Individual attention	Attending to individual student-TA interactions, without mention of group	I guess to just give the students more individual help. I imagine, well, I know that professors are much busier than TAs are, so they don't always have the time to like, address individual student concerns except maybe through email.

Individual needs	Working with individual student needs	So it's kind of trying as much as possible to... address students' individual needs in terms of what they don't understand, try to provide, since they're actually a person, they can provide different perspectives than the tutorial has, or explain things in a different way than the tutorial does.
Let students discuss	TA hangs back and doesn't interrupt	I oftentimes would not step in if I saw people explaining correctly to other people in the group. So if there was a good discussion going on, and they were fueling it themselves, then I wasn't so much trying to step in.
Listen to students	Attending to student ideas, not interrupting	I think the approach of listening to their conversation was good because it lets them kind of put out a whole bunch of different ideas, different ways of thinking it, instead of just supposing your way of thinking about it immediately.
Student collaboration	Students work together; emphasizing collective action on the part of the students	... if you can get to a point where even if neither of you know the right answer, but if you have a friend and you guys can both really talk about it, then I really feel like you can work through a problem that maybe neither of you would understand on your own.
Definitions	Textbook-like definitions	So they should go out knowing that the derivative of velocity is acceleration.
Equations	Equations & formulas	They just weren't in the mode where they were kind of thinking about these physics equations, and it was always hard to get people to recall.
Terminology	Formal physics language	... at least in the sense of the physics, all these specific little pieces have names. And sort of mixing them all up is... disastrous in some ways.
Making connections	Making connections and organizing understanding	They don't realize how much of physics takes place that isn't in like the tangible, visible world. It's really, a lot of it is about thinking, about connections, and about understanding things in a very different way than they're used to having to understand things.
Multiple representations	Coherence between visual, mathematical, verbal representations	I feel like people think physics is like all just math and like, I like to have people visualize, like, the equations. Like I know that sounds weird, and I think if you can visualize the equations you understand it a lot better, you can see what's happening in real life.

Problem-solving	Carrying out a problem-solving procedure	... well, because in CAPA, people get too involved with the numbers and they start writing down numbers, and they enter them wrong into their calculator and they don't arrive at a final symbolic expression for something.
Strategy	Plan for how to approach	...you kind of have some hypothesis, you go, "Yeah, I feel this system should behave in this way, you know, I'm trying to solve for the normal modes of some spring system and I know from the picture, the symmetries or whatever..."
Reflection	Reviewing consistency with previous result or earlier thinking	... and it's something you hope all the students go through: re-answering the problems and fully understanding what they did wrong.
Correctness	Focus on formal, correct answer	... there also has to be the complete given right answer, to make sure they have the total right picture in their head at the end. That's what I think.
Physical intuition	Reconciling with real-world examples or actual experience	Like when we did pressure this semester, one thing that was helpful was, for understanding that it only depends on depth, is so if you dive down to the bottom of a swimming pool, you know, it really hurts your ears, and it doesn't depend on what the sides of the pool looked like, or how wide the pool is, it's just how deep you go.
Multiple approaches	More than one way of thinking about it	Because if you really think you get it, and if you can explain it to the kid who has no clue what is going on, you truly do understand it and can approach it from enough different ways that I understand that you get it, and so does everyone else.
Checking off	Looking at student answers	[I] make sure they have the right things written down. That's kind of, well, one indication that I need to help them, or get them on the right track.
Quizzing	"Higher-stakes" checkpoint questioning	... one thing we did slightly differently than last semester was an extra tutorial on the forces, and it really helped them be able to draw forces and free-body diagrams, do the third law pairs and that kind of thing, so clearly it's helping.
Socratic questioning	Socratic dialogue, or "answering questions with questions"	So I would say that the role of the TA is kind of answering questions—or asking questions to answer questions.

Open-ended	Questions to explore or extend	I think in that tutorial we got into some of the more fun discussions about this, like, "This is really strange, why is this going on this way?"
Counterexample	Offering an alternative	Like, yesterday, I wouldn't give them the answer but I'd say, "Let's consider now, this."
Homework/exams	Homework & exam scores as indicators	I mean, there are really only 4 or 5 sample points for that, for the lecture—you've got these big tests.
Challenge question	Special, tough question to see if they get it	Yeah. [I] ask them questions, and make them explain it.
Behaviors	Changes in behavior, participation, reaction in the social setting	Yeah, it was really gratifying when people were like, "Oh, I really get this now, it makes so much sense!" And other times the looks become more glazed and it's like, (weak voice) "Oh, I should stop."
Abilities	Students become more able to do things	. . . one thing we did slightly differently than last semester was an extra tutorial on the forces, and it really helped them be able to draw forces and free-body diagrams, do the third law pairs and that kind of thing, so clearly it's helping.

These codes were then sorted into broader themes that could be compared against existing theoretical models in the literature (Table 4.2). We then refined definitions for codes until we were satisfied with the coverage of the data set. The final coding scheme constitutes the finest grain-size of the framework described below. See appendix C for sample coded data.

During the iterative coding process, we used a qualitative coding software package (*NVivo*) to analyze the interview data according to the developed rubric. Once we were confident in a rough framework for our interview subdimensions, we began coding transcribed video excerpts for similar types of themes. During this process, we consulted existing categorization schemes of teacher questioning and talk moves in the literature [5, 6]. Not all of the interview codes were useful or immediately applicable to our video data; in particular, we dropped the *Form* subdimension of Assessment because the coding themes (specifically the *Situated* codes) were too difficult to discern or occurred too infrequently in these settings to be meaningful. The practices coding rubric for each dimension will be discussed in the next section.

In order to assess reliability, a second researcher received 30 minutes of training before coding

Table 4.2: The arrangement of emergent codes into dimensions.

Emergent code	Merged code	Subdimension	Dimension
Explaining	Teacher	Agency	Agency
Pace setting			
Demonstration			
Authority			
Encouragement/motivation	Mixed		
Individual attention			
Individual needs			
Let students discuss	Student		
Listen to students			
Student collaboration			
Definitions	Factual	Knowledge	Goal
Equations			
Terminology			
Making connections	Conceptual		
Multiple representations			
Problem-solving	Procedural		
Strategy			
Reflection	Metacognitive		
Correctness	Answer-making	Epistem. Stance	
Physical intuition	Sense-making		
Multiple approaches			
Quizzing	Evaluative	Purpose	Assessment
Checking off			
Socratic questioning	Constructive		
Open-ended			
Counterexample			
Homework/exams	Isolated	Form (dropped)	
Challenge questions			
Behaviors	Situated		
Abilities			

two 40-minute TA interview excerpts. The researchers initially agreed on 83% of coded statements, which rose to 95% following a thorough discussion of the rubric and subsequent mediation of codes. The second researcher was then given a separate 20-minute excerpt to code, which resulted in 93% agreement.

A similar process was carried out for video coding: A second researcher was trained in the coding procedure and then given a 3.5-minute segment of video to code. After initial coding, the raters agreed on 78% of codes. Following discussion and mediation, the level of agreement rose to

97%. A second round of coding then resulted in 89% agreement between researchers.

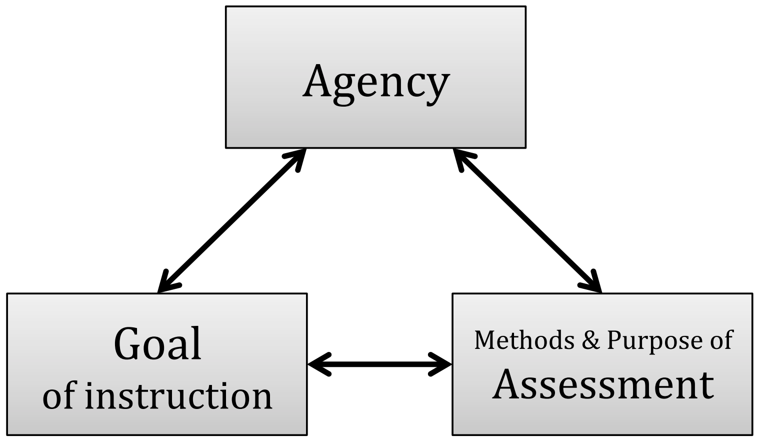

Figure 4.1: The dimensions of the TA-PIVOT framework, which may serve as anchors for the teacher's overall metaphor for teaching & learning physics.

Table 4.3: The complete TA-PIVOT framework, with broad dimensions in bold in the left column.

Agency	Agent	**Teacher**	Emphasizing teacher direction; teacher tells and students follow or listen.
		Mixed	Emphasizing student contribution
		Student	Emphasizing student collaboration and/or collective action
Goal of instruction	Knowledge	**Factual**	Basic knowledge involving memorization or recall (things you just need to "know").
		Conceptual	Connected, organized knowledge.
		Procedural	Knowledge to carry out a task or procedure.
		Metacognitive	Strategic, reflective knowledge of own thinking.
	Epistemological Stance	**Answer-making**	Focus on getting to formal, correct answer.
		Sense-making	Focus on reasoning and making sense of the answer, rather than the answer itself.
Assessment	Purpose	**Evaluative**	Assessment to evaluate following instruction
		Constructive	Assessment to inform practice or to guide learning

4.3 Results

4.3.1 Framework

The TA-PIVOT framework has three overall dimensions (*Agency, Goal, and Assessment*), along with subdimensions for each area (shown in Table 4.3). These dimensions are interconnected and may serve as anchors for overall perspective of teaching and learning (Fig. 4.1). As a means of introducing and describing the framework, we will examine each dimension individually for each of three TAs who served in the same semester of Physics 1110. "Sarah," "Daniel," and "Keith" (all names are pseudonyms) were first-year graduate students serving their second semester as TAs, none of whom had formal teaching experience before their first experiences as TAs the previous fall. In the previous semester, Sarah had also taught Physics 1110 whereas Daniel and Keith had taught Physics 1120 (E&M), the subsequent course in the series, also using tutorials.

This is not meant to serve as an exhaustive case study, but to demonstrate the utility of the framework and describe the dimensions in further detail. These dimensions are fully described in the beliefs section, along with representative quotations drawn from interviews. We then follow with illustrative examples to examine the same TAs' instructional practices, along with summaries of their overall observed practices across a week of episodes (Week 7, including 31 total videos). Finally, we will show side-by-side coding results for beliefs and practices using the same framework. In the next chapter, we will examine the overall consistency of beliefs and practices, highlight variation among TAs, and track the development of TAs' beliefs and practices over time.

In assessing the utility of our coding schema, we report on our ability to distinguish differences in coding distributions for individual TAs. The purpose of this step is to verify that differences between TAs don't wash out. In other words, we wish to report on our confidence that the differences in observed coding distributions reflect actual differences between individual TAs and not random chance. In this section, we will use the Fisher's Exact Test [7], a version of the chi-squared significance test that is commonly employed for categorical data with small sample populations, to calculate p-values for differences between indivdual TAs along each dimension.

4.3.2 Application of Framework: TA Beliefs

4.3.2.1 Agency

Agency is defined in the literature as the socioculturally mediated capacity to act [8]. In examining agency, we are concerned with who is intended to be active and influential in the learning process. We acknowledge that in the environment under consideration, both TAs and students are constrained in their possible modes of participation, and thus our definitions of agency are therefore subject to local context. For example, students and TAs are not free to choose the content of the tutorial they work on each week, or even whether or not they use tutorials at all. However, we argue that within this classroom setting there is sufficient latitude for instructors to establish norms for participation through their use of discourse and tools. In doing so, we build on prior work that demonstrates how instructors' implementation of Peer Instruction in this same course influences students' perception of classroom norms [9].

Table 4.4: Practices coding rubric: Agency

	Code	Practices subcodes	Practices example
Agency	**Teacher Agency (AG1)** Emphasizing teacher direction; teacher tells and students follow or listen. Teacher decides when to stop/start discussion.	▷**Explanation** (TA extended talk w/o bid for student response.) ▷**Pass judgment** (TA decides what is correct/incorrect) ▷**Giving direction** (Explicit instruction on what to do) ▷**Cuing** (providing a hint, unprompted)	"The Work-Energy Theorem says W equals delta KE. And Work is Force times distance. And we know the force is the same and the distance is the same. So the work is the same."
	Mixed Agency (AG2) Some level of mutual action by teacher & students	▷**Restating** (paraphrasing student response) ▷**Recapping** (restating shared information) ▷**Informed cuing** (Cuing based on student feedback)	"And like you were saying, the work done is the same." "And we know from before that the carts take the same time to cross."

	Student agency (AG3) Emphasizing student contributions, student collaboration, and/or student self-direction. Teacher hangs back or imposes limits on own action	▷**Elicitation** (What do you think?) ▷**Externalize reasoning** (Valuing student reasoning) ▷**Positioning** (Having students respond to students)	"Why do you think it's seven?" "Do you guys agree with what Bob just said?"

Generally speaking, we use this dimension to examine whose contributions are valued and given attention during a classroom interaction. For example, in an interview, one TA stated that their role should be to "step in and tell them how I would do it," which would be coded as *Teacher-centered* agency because it places the clear value on TAs' ideas over the students'. In contrast, a statement that "students should work collaboratively and the TA should not interfere" was coded as *Student-centered* agency because it downplays the TA's role while emphasizing students' collective action. Statements that were coded as *Mixed* involved mutual TA-student action or did not give a clear indication whose contributions were preferred.

In describing her approach to teaching during an interview, Sarah placed an emphasis on supporting groups in working together to complete the tutorial. Her role as a teacher is "facilitating [the students'] discussion" and she described how she is careful not to interrupt an ongoing student discussion. She did note that there are times when the teacher should explain or provide examples, but says that it is best when such ideas are student-generated. The following quote reflects Sarah's interest in listening to student ideas:

> I think the approach of listening to [the students'] conversation was good because it lets them kind of put out a whole bunch of different ideas, different ways of thinking it, instead of just supposing your way of thinking about it immediately. [Sarah post, 00:10:39]

In contrast, Daniel and Keith's stated beliefs reflect a strong emphasis on their own agency in a student's learning process. Daniel described how students should initially work together in struggling through challenging problems, but his role is then to "tell them how I think about it, so they can see how my mind works." Furthermore, Daniel stated that it is important for the TA to know the material "cold" because if he needs to pause and think in front of the students, then they will stop paying attention. Daniel described himself as "not interested" in hearing students' incorrect responses, preferring to step in with a correct explanation:

> I would prefer to see that they got to the wrong track and then get them to the right spot, and then [have] me tell them the way I would think about it, correctly, rather than hear them like, talk about and go around in circles about stuff and try to follow where they were going. I would prefer to just get to the point where the confusion set in and tell them how I did it, and then hear them go, "Ohhh. . . okay." [Daniel post, 00:32:12]

Similarly to Daniel, Keith states that a primary role of the TA is answering student questions. He expressed surprise that some of the Learning Assistants he worked with were not always able to answer student questions:

> I guess, initially I was expecting [the LAs] to be able to answer all the questions the students had, and then I realized, well, maybe that's not their job, that's the TA's job. [Keith post, 00:37:20]

Fig. 4.2 compares the coding results for each TA's beliefs along the dimension of Agency. We present absolute counts of codes for Agency during the interview session; additionally at the top is the fraction of codes of Agency out of the total number codes across all dimensions. Sarah's distribution of codes are statistically different from Daniel and Keith's; Daniel and Keith are not statistically different from one another.

4.3.2.2 Goal of instruction

Goals and intended outcomes are a widely recognized component of instructor beliefs [10]. This dimension corresponds to the intended outcome of the learning process, and represents a condensed version of the taxonomy of the cognitive domain drawn from Anderson [11]. Within this dimension, we also separate instructors' content-based goals from their epistemological stance toward answer-making or sense-making [9].

Although the tutorials themselves are conceptually focused, other forms of knowledge are emphasized in various other course components. For instance, weekly homework sets assigned

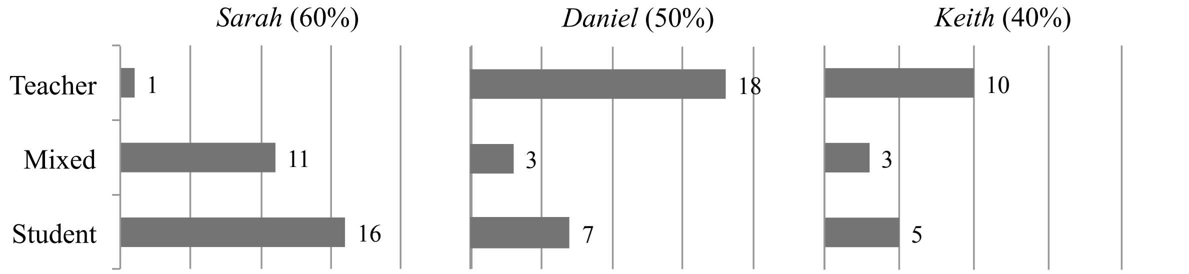

Figure 4.2: Coded instances of beliefs along the Agency dimension for Sarah, Daniel, and Keith. Percentages describe the fraction of overall codes for each TA that were coded under Agency. Using Fisher's exact test, Sarah's distribution of codes are statistically different from both Daniel's ($p < 0.0001$) and Keith's ($p = 0.0003$). Daniel and Keith's distributions are not significantly different from one another.

through the CAPA online homework system [12] emphasize traditional physics problem solving with numerical answers and no prompt for explanation. TAs may choose to integrate these other cognitive levels within the tutorial setting, or keep them separate.

Table 4.5: Practices coding rubric: Goals

	Code	Practices subcodes	Practices example
Knowledge	**Factual (GK1)** Basic knowledge involving memorization or recall (things you just need to "know")	▷**Definition** (Textbook-like definition) ▷**Terminology** (Formal language) ▷**Equation** (Physics equations, in a plug & chug way)	"Acceleration is the rate of change of velocity." "You mean velocity is increasing." "The formula for KE is $1/2\, mv^2$."
	Conceptual (GK2) Connected, organized knowledge.	▷**Concept** (Connected, organized ideas) ▷**Model** (Using a model or abstraction)	"How does Newtons second law apply here?" "Let's draw a free-body diagram for this situation."
	Procedural (GK3) Knowledge to carry out a task or procedure.	▷**Strategy** (Plan of how to get "there") ▷**Mathematics** (Use of mathematical formalism)	"Here's how were going to solve this problem. First, we. . . " "How do we use the dot product here?"
	Metacognitive (GK4) Strategic, reflective knowledge of own thinking	▷**Reflection** (What are you doing? Why are you doing it?) ▷**Projection** (What are you going to do w/ it?)	"Is this consistent with the previous page?" "How will we use this result?"

Epistemological Stance	**Answer-making (GE1)** Focus on getting to formal, correct answer	▷**Confirming result** ▷**Checking** (Got it/don't got it)	"Do you understand?" "Right. The answer is seven." (No reasoning present)
	Sense-making (GE2) Focus on reasoning and making sense of the answer, not just the answer itself	▷**Chaining** (Understanding steps) ▷**Reasoning** (Focus on student reasoning)	"How do you know thats the result?" "How does that follow from this?"

As shown in Fig. 4.3, Keith spends a significantly longer time than other TAs describing what he wants students to learn about physics (40% of overall codes vs. 20%), indicating that his goals for students appear to be a focal component of his beliefs about teaching. Here is how he responds to a question about what he finds most and least useful about the UW tutorials:

> Sometimes I feel like the way [the tutorials] introduce the equations, or prompted the students to write down equations or start doing math was not the best way of doing it… [The students] just weren't in the mode where they were kind of thinking about these physics equations, and it was always hard to get people to recall. You know, I'd be like, "This makes sense because, well, what is momentum equal to, in terms of mass and velocity?" They'd be like, "Ummm," they'd have a hard time thinking about that kind of stuff. I guess I feel like having more problem solving and mathematics kind of informs the intuition and vice versa, it's good to have this kind of back-and-forth way of thinking about it. [Keith post, 00:23:42]

In this quote we see a sampling of the type of understanding Keith wants students to develop. First, there is an explicit focus on *Factual* knowledge, in that Keith wants students to be able to recall formulas when they need them. In addition, he expresses that activities that focus on problem-solving support the development of physical intuition in a "back-and-forth" way. We coded this as a combination of *Procedural* and *Conceptual* knowledge.

Compared with Keith, Daniel spent less time describing the types of physics knowledge he expects students to use and learn in the classroom, but he expressed confidence in what he did say (Verbal stress indicated):

> For instance, I'll set up a Newton's Laws problem where you have forces and I'll say, "This is the way you always do it, you always set up the free-body diagram, then you always write down each component of the Newton's Second Law, and

> then once you've got that all written down, the next step is to try and combine it in ways..." [Daniel post, 00:16:18]

Here we see a clear focus on *Procedural* knowledge, but in a more fixed, rote manner indicative of *Factual* knowledge. Effectively, Daniel is emphasizing a process for students to internalize rather than adaptable strategies that students can reconstruct.

Sarah also emphasized students' problem solving abilities, but discussed it in the context of connecting concepts learned in the tutorial setting to solving the types of traditional physics problems that appear on the weekly homework assignments:

> ...just because [students] have to do that for the exams and things, or they just read a problem and they're like, "I know about these concepts, but I have no idea how to connect it to a problem, or what to look for in this problem that tells me what concepts I need." And some of that might be they need to get used to doing that kind of problem and it will come as they take more physics classes. I think that was difficult for some students. [Sarah post, 00:26:47]

In this way, Sarah appears similar to Keith in valuing *Procedural* and *Conceptual* knowledge. Sarah also found ways to reconcile physics concepts with students' experiences outside the classroom, such as in this example:

> Like when we did pressure this semester, one thing that was helpful was, for understanding that it only depends on depth, is so if you dive down to the bottom of a swimming pool, you know, it really hurts your ears, and it doesn't depend on what the sides of the pool looked like, or how wide the pool is, it's just how deep you go. So that was very helpful for people. [Sarah post, 00:37:12]

Here, using prior physical experience to understand a feature of pressure was coded as valuing *Sense-making*.

Procedural knowledge was the only subdimension mentioned by all three TAs, mostly having to do with students' abilities to solve traditional computational physics problems. This sentiment was common among the interviewed TAs; there is support for developing students' problem solving skills, although there are differences in opinion on what role the tutorial should play in that process. Keith expressed that there should be more traditional problem solving during the tutorial sections, going as far as to suggest that part of the recitation time be dedicated to showing examples of how to set up and solve mathematical physics problems. Sarah thought that the tutorials already serve a role that is complementary to traditional problem solving.

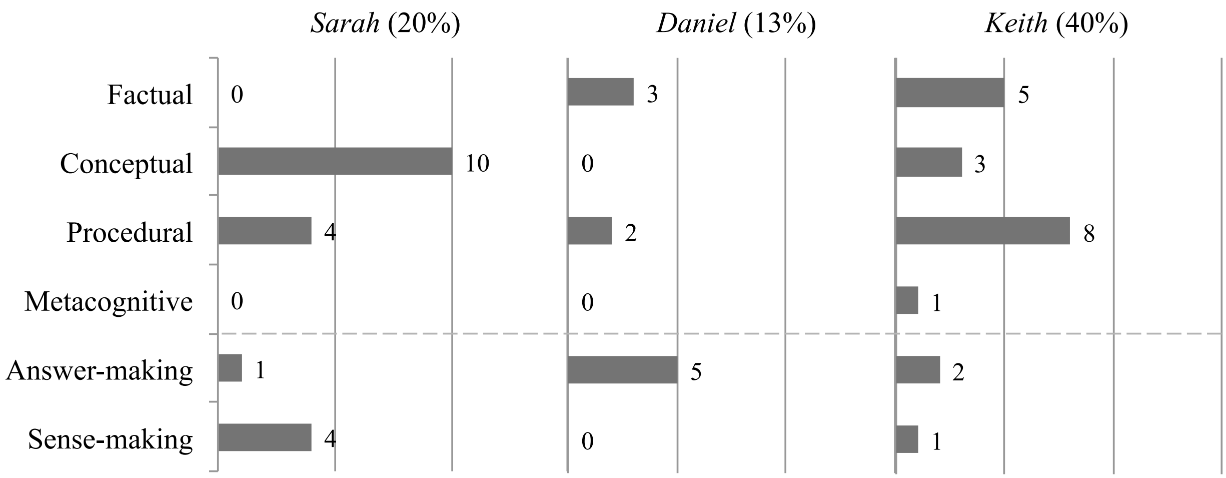

Figure 4.3: Beliefs along the Goal dimension for Sarah, Daniel, and Keith, drawn from interview data. Percentages describe the fraction of overall codes for each TA that were coded under Goal. The distributions which are statistically different are Sarah and Daniel's epistemological stances ($p < 0.05$).

4.3.2.3 Methods & purpose of assessment

Assessment is a critical component of teaching practice [13]. In this dimension, we consider how an instructor gathers information about a teaching situation, and to what end this information is to be used. For example, an instructor may assess student understanding by reading what they have written in their tutorial book; by gauging their response to challenge-type questions; or by observing their manner of participation in a group. This dimension includes the ways in which TAs use questioning to understand classroom situations, and also encompasses broader perspectives on the role and nature of assessment in instruction.

In examining TAs' practices along Assessment, we primarily attend to the forms of questioning that TAs use when interacting with students. A common pattern of teacher-student discourse is the *Initiate-Response-Evaluate* (IRE) form [14, 15] that provides minimal feedback and tends to constrain student responses along a pre-determined path. Here is an example of an IRE "chain" drawn from one of our episodes:

> **TA:** Alright, so in that [question], what's the work done on A? *(Initiate)*
>
> Student: Positive. *(Response)*
>
> **TA:** OK. And then on B. *(Evaluate, Initiate)*
>
> Student: Positive. *(Response)*
>
> **TA:** OK, so then if I define the net work to be the sum of those two, that has to be. . . what? *(Evaluate, Initiate)*
>
> Student: Just A plus B? *(Response)*
>
> **TA:** OK, yeah. *(Evaluate)*

Some TAs use challenge questions or "quizzes" at checkpoints or at the end of tutorial to determine whether students are done with a tutorial or section. TAs can also evaluate student responses without questioning. For example, TAs often examine students' written responses in a "checking" manner to evaluate their understanding. We code all of these strategies as emphasizing an *Evaluative* approach to Assessment.

In contrast, teacher questioning can be also be used to expand discussion, challenge student thinking, or provide constructive feedback.

> **TA:** Let me ask you guys something. So what if I told you that on this problem, B_3 actually had the longest velocity vector, B_2 had the middle, and B_1 had the shortest. Would your answers change?
>
> Student: Yes they would.
>
> **TA:** How?

The TAs' questioning in this case is intended to advance the discussion rather than evaluate correctness. These also include questions that extend beyond the tutorial, or ask students to consider "What if...?" in a previously established context. These forms of assessment were coded as a *Constructive* approach.

We have avoided using strict categorizations of summative vs. formative assessment here, for two primary reasons. First, we find that the TAs do not use this terminology themselves, as it is not an explicit focus of current TA preparation methods. Second, it can be difficult to identify these forms of assessment based on observed practices alone. Instead, we identify features of assessment that can be more readily observed, and these can be mapped onto commonly identified components of formative and summative assessment.

Table 4.6: Practices coding rubric: Assessment

	Code	Practices subcodes	Practices example
Purpose	**Evaluative (AS1)** Test understanding w/ minimal feedback	▷**Checking** (Looking at answers only) ▷**I-R-E** (Initiation-Response-Eval form of questioning) ▷**Quizzing** (Tough question to evaluate understanding)	"The kinetic energy is the same, right?" "What is the acceleration at the top of the ramp?"
	Constructive (AS2) Explore ideas, inform practice	▷**Open-ended** (Answer space is open) ▷**Challenge** (Counterexample) ▷**Extending** (Question goes beyond tutorial)	"How did you solve this problem?" "When have you seen this in real life?"

In this quote, Keith describes a particular way that he assesses student understanding:

> [The students] had a hard time understanding what the new words, their meaning in physics class meant, as in understanding that things like velocity and acceleration were very precise terms that meant something. And that they're supposed to be used in certain contexts. And oftentimes they would use colloquial vocab... they would just use kind of everyday... I'm trying to think of an example, but you know, they would say "pushing" or "pulling" instead of like, "tension force" or something like that... stuff like that. With motion especially in the beginning I remember it was pretty bad. I don't remember which words they used, but they were, they would never say "velocity," "acceleration," and then that I think would confuse some people, they would get confused about speed and velocity because they wouldn't get in the habit of using physics terms. [Keith post, 00:07:34]

To Keith, students' use of informal language is an indicator of a lack of understanding. This is interesting framing on Keith's part because he is conducting assessment based on students' forms of participation in the social setting *(Situated)*. The language he uses, however, is indicative of a more summative perspective on assessment, as he does not describe how he might build upon students' everyday vocabulary to help them move toward using physics terminology. This is coded as *Evaluative* assessment, rather than *Constructive.*

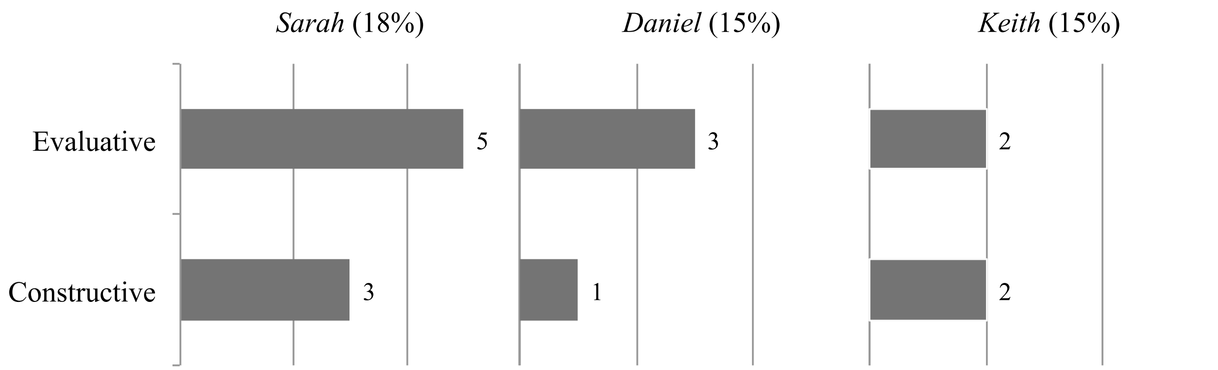

Figure 4.4: Beliefs along the Assessment dimension for Sarah, Daniel, and Keith. Percentages describe the fraction of overall codes for each TA that were coded under Assessment.

Sarah also describes how she uses questioning in particular ways:

> Or also, sometimes we came up with interesting questions to ask people who finished early, which was kind of fun. Or questions you can ask to try to deepen intuition of, or gauge their understanding of it without just asking the answer to the question in the tutorial. [Sarah post, 00:40:56]

In Sarah's view, questioning can serve as a means to "gauge understanding" *(Evaluative)* but also to "deepen intuition" *(Constructive)*. Sarah also described in her interview how part of her role is "asking questions to answer questions," which also reflects her belief in using questions to drive discussion in addition to evaluating student understanding.

Compared to other teaching components, the TAs are less explicit in describing their beliefs about assessment in the classroom. In the absence of ongoing pedagogical training, these TAs appear unaccustomed to terms (and concepts) such as "formative" or "summative" in describing their own assessment practices. In fact, these terms were not mentioned in interviews with any of the 13 TAs who were videotaped. We note that Sarah tends the most toward emphasizing more formative types of assessment, although both the amount and variation are not as great as in other dimensions.

By looking across these dimensions holistically, we can paint a broader picture and infer a more recognizable (if not stable) model of the TAs' teaching philosophies. for example, We described previously how the relative focus of each TA on these dimensions provides insight as to their overall model of teaching. For instance, Keith's focus on content goals (using interview talk time and number of codes as an indicator) are reminiscent of the teaching model that Kuhs and Ball [16] describe as *content-focused with an emphasis on performance.* In this model, student mastery of mathematical rules and procedures is emphasized, with the instructor serving primarily to demonstrate and model problem solving tools and methods.

While we do not argue here for a robust and consistent model of *beliefs*, we can use these dimensions to more carefully examine TA practices, thereby allowing us to consider TAs' described and enacted models of teaching side-by-side. In the next section, we examine TA *practices* through the lens of the TA-PIVOT framework.

4.3.3 Application of Framework: TA Practices

To illustrate the application of the TA-PIVOT framework to TAs' instructional practices, we use it to analyze several classroom episodes. In practice it is useful to examine complete episodes of TA practice and then unpack the observed practices in that episode across each of the three dimensions. We first provide examples of how this is done, and then present the coding results for TA practices.

While all TAs were asked the same questions in an interview and each interview lasts roughly same amount of time, we do not have the same control over how much video data is captured for each TA, given the live nature of these observations and the varying amount of time that each TA decides to spend at each table. We account for this effect by: *a)* capturing many episodes from each TA, including multiple sections and groups of students (a minimum of 3 different student groups from each week); and *b)* normalizing the frequency of each TAs' practices codes relative to the overall time they spend interacting with students. (The frequency of TA interactions is a supplementary indicator of agency, although we do not report on this directly here.)

We begin by considering one particular topic area covered by each of the TAs during Week 7 of Physics 1110, after which we will summarize the video coding results across all observed episodes captured from videotape data during that week. The following vignettes are drawn from the "Work

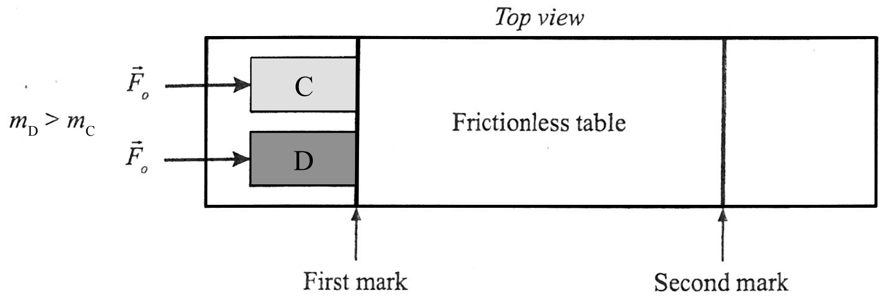

Figure 4.5: Figure from “Work and changes in kinetic energy” tutorial.

and changes in kinetic energy” tutorial [17]. In this tutorial, students are presented with a scenario in which a force F_0 is applied to two blocks, C and D ($m_C < m_D$), as they move between two lines on a frictionless table (Fig. 4.5). In the question under consideration, students are asked to agree or disagree with a student who claims that block C will have a greater kinetic energy than block D at the time they each cross the finish line. On the next page, the tutorial prompts the students to check the consistency of their reasoning with the work-energy theorem.

We consider this question particularly interesting to focus on because it provides a classic example of the UW tutorial “elicit-confront-resolve” model, in which students are presented with a question that is known to commonly elicit incorrect ideas; then prompted to consider an alternative explanation; and finally guided toward resolving the inconsistency [18]. Very often these types of questions present a dilemma for TAs to “troubleshoot” student reasoning on the spot or allow students room to persist with incorrect ideas knowing they will be prompted to resolve it on their own.

Daniel

[Daniel sits down at a table where S1, S2 are seated.]

Daniel: Do you guys feel good about the one on the previous page, this guy? You agree! Uh oh.

S1: Yeah, see, I didn’t want to agree.

D: So, let's think about this. So, we know that the force is the same on each block, right?

S1: Yeah.

D: And we know the distance the blocks travel is the same.

S1: Right.

D: So, what's work? Force times distance. And work is equal to change in kinetic energy.

S1: Right.

D: So if the force is the same on both and the distance traveled is the same on both, the work done on both—

S1: Is the same.

D: —is the same. Which means the change in kinetic energy of both is the same.

S2: But if you look at it, like $F = ma$, then wouldn't the acceleration of one have to be bigger than... delta KE, 'cause like $1/2\, mv^2 \ldots$

D: It's not totally obvious how you would relate the acceleration from, to the velocity. But you *can* apply this principle that the change in kinetic energy is equal to work done.

[S1, S2 erase their previous responses and respond again. Daniel waits a few moments and leaves.]

We notice immediately that this interaction is very brief, and that almost every 'correct' or scientifically accepted contribution to the discussion comes from Daniel. Note that upon observing that the students had responded incorrectly to the first question, he chooses to explain in detail his own reasoning instead of asking them to explain how they reached their conclusion. Throughout this conversation, Daniel provides few opportunities for the students to express their own ideas, apart from agreeing or disagreeing with his explanation. In Line 10, he even answers his own question. Furthermore, when S2 raises a salient point about the relative motion of the two blocks (Lines

17-18), Daniel does not address the underlying student idea. We code each of these practices as emphasizing *Teacher agency*.

Daniel's goals in this episode focus on the expressions for work and the work-energy theorem *(Factual)*, along with demonstrating the logical progression *(Conceptual)*. With regard to epistemology, this interaction is geared toward "fixing" the students' incorrect responses *(Answer-making)*. Finally, although Daniel asks no questions during this episode, he initially uses the students' written responses to assess their understanding *(Evaluative)*.

It's worth noting that this interaction is almost identical to one from another of Daniel's sections during the same week:

[Daniel approaches table.]

S1: Can we like, check this with you—

Daniel: Yes.

S1: —like, that that's right?

D: You say—

S1: We said that we agreed.

D: Right.

[TA pulls up a stool and sits down]

D: Uhh, sooo...

D: On these two blocks, we know there is the same force. *[Points at diagram in S1's book]*

S1: Yeah. *[Nods emphatically]*

D: Right? And we know these two blocks travel the same distance.

[S1 nods]

D: So that means that the work done on the two blocks is exactly the same. And if the work done on the two blocks is exactly the same, it means that their changes in kinetic energies are exactly the same.

S1: Ohhhhh.

D: So if the changes in kinetic energies are exactly the same, then the student's wrong.

[S1 and others at table erase their previous response]

In particular, Daniel's step-by-step explanation from Lines 10-21 is reused almost verbatim from the previous example, and is triggered by the same observation that the students agreed with the incorrect student statement from the tutorial. This pair of episodes illustrate the type of "scripted" interactions that can be common for instructors, even in transformed environments. In this case, Daniel appears to have a practiced explanation for this question that he applies upon observing incorrect reasoning.

Sarah

We previously observed that Sarah's stated beliefs were different than Daniel and Keith's, so we can examine her interactions with students to see if these differences hold up in practice.

Sarah: So what did you think about the kinetic energies of the two [blocks]?

S1: They're different, but we can't tell which one's greater and which one's less because we don't know how much. . . *[moves hands alternately up and down]*

S: So how do you know they're different?

S1: They both have different masses and different velocities.

S: Okay, but what do we know about the work done?

S1: The same.

S: And we had this work-kinetic energy theorem. So if we just look at that, it seems like the kinetic energies ought to be the same.

S4: The change in kinetic energy should be the same.

S: Right. So if they start at zero velocity. . .

[S1 erases a previous response.]

S3: And it's zero kinetic energy.

S4: So the final kinetic energy should be the same.

S: Right. So is that consistent with what we were talking about? We don't really know a whole lot about. . . I guess you could work it out carefully, but it's sort of not very easy to see.

S4: Yeah. Yeah.

S: And that's why we do this work-kinetic energy thing, is because it makes a really simple way to solve some problems.

S4: Okay. So the kinetic energies are the same. *[To Sarah]* Right?

S: Right.

S4: Because the net work is the same, the change in kinetic energies are the same.

S: And what you guys were thinking about was right, it's just it's hard without knowing specifics to say exactly what the velocity and mass relationship is, but it should work out to be this exact same answer. Looks good.

[Sarah leaves the table.]

This episode illustrates a few features of Sarah's teaching. First, she gives explicit attention to student reasoning (Line 4), prompts for reflection (Line 15), and validates student thinking (Line 24). Each of these practices is aligned with an emphasis on *Student agency.* However, the overall interaction is centered around guiding students toward a particular result, in a similar manner to Daniel in the preceding excerpts. Sarah also alludes to problem-solving (Lines 19-20) *(Procedural)*, and self-consistency (Line 15) *(Metacognitive)*. Furthermore, we coded her bypass of the kinematic approach (Lines 24-26) as aligned with *Answer-making.*

There is another pattern of interaction Sarah tends to follow, which is a "checking" mode in which she reviews a page of the tutorial with the students, as in this episode:

Sarah: Do you want to [go over the third page] real quick?

S2: Yeah.

S: OK. So did you go over page 42?

S2: We didn't. Do you want to go over that really quick too?

S: Cool. Alright, so in that one, what's the work done on [block] A?

S2: Positive.

S: OK. And then on B.

S2: Positive.

S: OK, so then if I define the net work to be the sum of those two, that has to be... what?

S2: Just A plus B?

S: OK, yeah. So it's like some positive non-zero number. So—but what's the net force on the system?

S2: Zero.

S: So, how is that consistent? There seems to be some reason that I can't calculate the net work from the net force. So what would that be?

S3: Can you ask that question again?

S: Yeah. So it looks like if I tried calculating net work from a net force that equals zero, I kind of expect—

S2: The net work would equal zero?

S: So there's some reason that the net force doesn't tell me about the net work.

S2: Because you have to consider the objects independently?

S: Yeah, and so we know, force has a direction, right?

[S2 nods]

S: Does work have a direction?

S2: No. In the sense that it matters which direction the force and displacement are going, but not—

S: Right, but it doesn't have its own direction. Like, you can't say work is pointing at 45 degrees—

S2: Right.

S: OK. So, work is kind of a scalar. So if you add two scalar quantities, as long as they have the same sign, they're not gonna cancel out. But for a vector, the direction matters, right?

S2: Right.

S: So if I add two forces, then they can cancel. But the work doesn't necessarily—so that's why you consider them independently.

We observe in this episode that Sarah is asking primarily short, recall-based questions focusing on *Conceptual & Procedural*, with an occasional check for consistency *(Metacognitive)*. Furthermore, although three students are seated at the table, she engages almost exclusively with S2. The differing nature of these interactions results in the more mixed approach to agency in her overall classroom practices.

Keith

TAs sometimes make their content goals immediately apparent through their classroom practices. In this episode, Keith interacts with a group who has completed the tutorial about 10 minutes early:

Keith: You guys are done?

S2: Yeah.

K: Totally done?

S3: Done with what?

S2: We're speedy physics-doers.

K: Alright. Then you get the bonus—the bonus tutorial.

S2: Can we just do CAPA?

K: You can just do CAPA. This will take—this will only take a couple of minutes.

S3: We only have a couple of minutes.

LA: You still have ten minutes to go.

K: You still have ten minutes.

S2: Yeah, that's why we're going to do CAPA.

K: This will take up a few minutes. Ready? OK. If I told you this, would you believe me: kinetic energy—

S3: No. (laughs)

K: —final is equal to kinetic energy initial plus delta kinetic energy.

S2: Initial plus. . .

K: Initial plus the change is equal to final, right?

K: Because final minus initial—

S2: Right. Right.

K: —is equal to the change. So I just. . . OK?

S2: Yup.

K: Delta KE, what do you know it is from this tutorial?

S2: Uh, work.

K: OK, so, kinetic energy final, how can we write that in terms of m and v?

S2: In terms of what?

K: m—

S2: $1/2\, mv^2$.

K: Yeah. $1/2\, mv$ final squared. Same thing for initial. $1/2\, mv$ initial squared. Plus work.

K: What's work in terms of force and distance?

S2: Force times distance. Force times displacement.

K: Force times distance. We're talking in one dimension, so let's just do force times distance, pretend that the cosine theta. . . So the work becomes "plus force times distance".

K: What's force?

S2: Mass times acceleration.

K: Does this equation look familiar?

S4: Yes it does.

K: What if we were to cancel out the m's…and multiply everything by 2?

S2: v final equals v initial plus $2ad$. Look at that! Whaaat?

K: So you don't need to remember this now, because you know this. So you can always go from here to here.

S2: Cool.

K: First equation, and then just…So you need one, two, three, four equations. And you can get from here to here.

S2: Cool.

K: But you know all these things, these are really simple, you can remember them all.

K: That's the bonus lecture. So you're probably wondering why doesn't this have time in it, where the heck does it come from when we first learned it, it comes from kinetic energy.

S2: Sweet.

What we observe in this episode is basically an extended lecture on Keith's part, with a clear focus on mathematical derivation. Although it is not immediately apparent from the transcript, the screenshot in Fig. 4.6 illustrates how Keith is writing out each line of the proof while the students watch *(Teacher agency)*. Keith is demonstrating a proof of an earlier kinematic equation using newly introduced work-energy principles *(Conceptual & Procedural)*. Keith provides frequent prompts for student contributions (Lines 23, 25, 31, and 36), but they are all closed-form questioning serving to fill in the blanks along his pre-determined path *(Answer-making)*. In Line 42, Keith gives his motivation for showing the students this proof, which is to remember the more general formula instead of the old one *(Factual)*. Keith's students do not seem to share his enthusiasm for this

Figure 4.6: Keith demonstrating a proof.

proof; toward the end, S2, who was the most persistent about moving on to the CAPA homework, makes repeated attempts (Lines 44, 47, and 53) to disengage from the conversation.

These vignettes represent a subset of the episodes coded for the "Work & changes in kinetic energy" tutorial. Each of these episodes can be coded using the TA-PIVOT rubric, and we do so in order to observe overall patterns. Fig. 4.7 illustrates coding results for Sarah, Daniel, and Keith's instructional practices across all three dimensions for all Week 7 episodes.

We first observe that the TAs tend to emphasize teacher agency in the classroom—in particular Sarah, who on average spends the longest time at each table. Although she asks questions frequently and allows ample time for students to respond, Sarah also dedicates a large portion of time to directly explaining or clarifying ideas to students. In once instance, a group interrupts her in the middle of an explanation to say, "We think we get it."

With respect to TAs' goals, there is a clear emphasis on factual, recall-based questioning among the TAs. In fact, Daniel relies exclusively on testing students' factual knowledge during week 7, whereas Sarah and Keith demonstrate an additional but relatively more limited focus on students' and procedural understanding. This is somewhat surprising due to the conceptual focus of the tutorials, and encourages us to think about TAs' reliance on this lower-order cognitive domain.

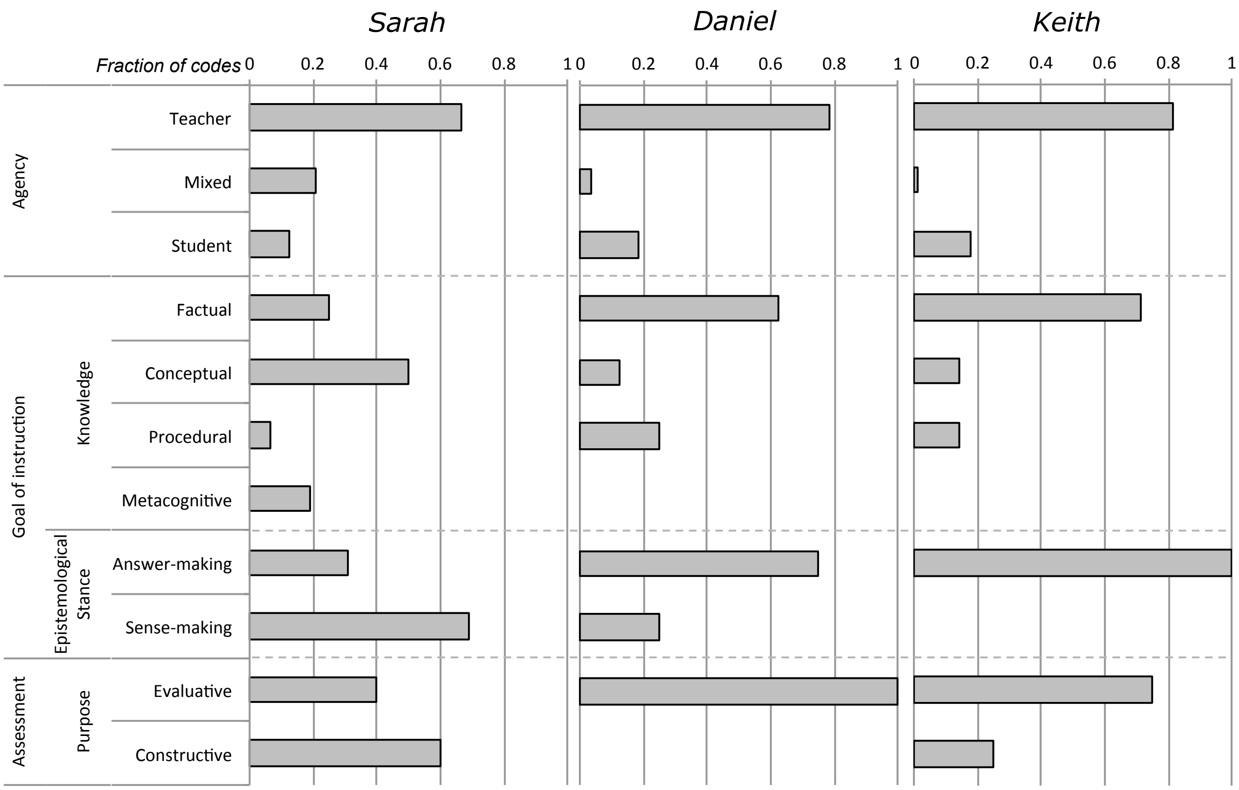

Figure 4.7: A summary of coding results for Sarah, Daniel, and Keith's practices. Codes are normalized within each subdimension (separated by dashed lines). Sarah and Keith's epistemological stances are statistically different ($p < 0.05$), and Daniel's knowledge goals are different from both Sarah's ($p < 0.05$) and Keith's ($p < 0.05$).

Additionally, Sarah's practices are tend to emphasize students' ability to interpret and make sense of physics content, whereas Keith's practices focus on the correct, scientifically accepted answer.

There are also clear differences among the TAs' preferred forms of assessment. Daniel relies exclusively on student responses to his checking-style questions, as well as their written answers, to gauge understanding. Sarah and Keith are more mixed in attending to students' forms of participation in the class, as well as direct questioning, to inform their practice. In the case of Daniel and Keith, this questioning tends to take a more closed *initiate-response-evaluate* form [14] that constrains student responses along a pre-determined path. Although Sarah also engages in this style of questioning, we also observe her using questions to open the discussion further in a more formative manner.

4.3.4 Comparing beliefs & practices

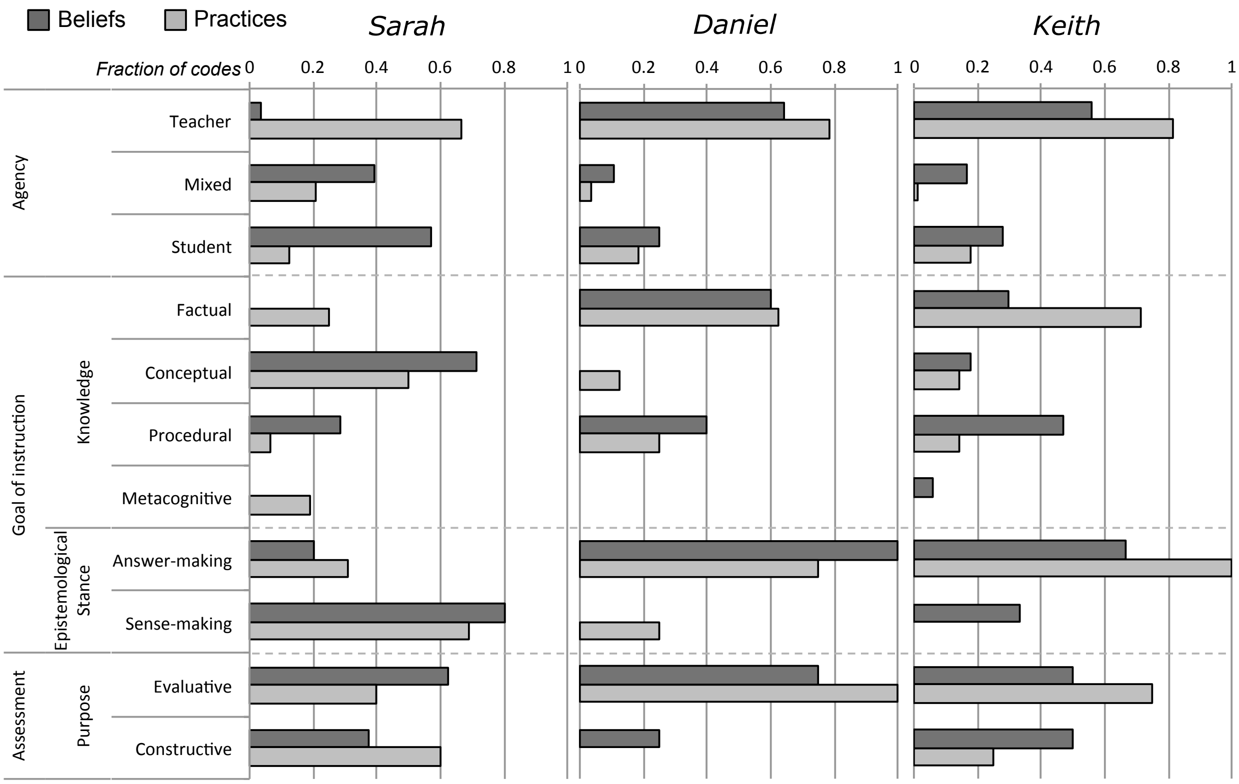

Figure 4.8: A complete comparison of Sarah, Daniel, and Keith's beliefs and practices. Codes are normalized within each subdimension (separated by dashed lines).

A complete summary of the beliefs and practices coding for these three TAs is provided in Fig. 4.8, and allows us to compare the coding results for each domain side-by-side. While we save a detailed examination of the coordination of beliefs and practices for the following chapter, we demonstrate the capacity and potential utility of this framework to simultaneously examine beliefs and practices here.

Daniel and Keith's observed practices related to agency appear relatively well-aligned with their stated beliefs, both of which emphasize teacher agency. However, they are inconsistent with the intended approach of the tutorial, which is to allow students the opportunity to externalize their own reasoning and resolve disagreements and inconsistencies amongst themselves. In comparison, Sarah is aligned with the tutorials in her stated beliefs but not as well in her practices. Examples like Sarah's illustrate how challenging it can be to consider and apply pedagogical intentions "in-the-moment."

Compared to the interview setting, all of the TAs shifted more toward emphasizing factual knowledge in the classroom. We also observe indications of consistency between beliefs and practices in TAs' epistemological stances. For instance, Daniel was coded as only answer-making in the interview setting, and he had a relatively higher fraction of this code in practice; the same was true for Sarah along sense-making. In this instance, Sarah is coordinated with the curriculum in both her beliefs and practices, which may indicate a productive foothold that could be used to help her align other aspects of her instructional practices with her beliefs.

Our earlier observation regarding the TAs' lack of focus on assessment in their beliefs appears to carry over to their practices as well, where we see that questioning is not a focal component of TA practices. When it is, it is primarily used to assess student understanding rather than allow an opportunity to expand the discussion. This result is surprising to us, given the critical role of assessment—particularly formative assessment—in instruction. This finding motivates us to reflect on current TA preparation methods and consider how discussions of the assessment accompanied by efforts to incorporate them into ongoing practice would be productive in increasing TA attention to beliefs and practices surrounding these constructs.

Furthermore, we find that TAs in these environments may exhibit surface support or buy-in to transformed curricula while exhibiting beliefs and practices that appear contrary to the pedagogical intent of that curriculum. Daniel is one example of a self-described supporter of the *Tutorials in Introductory Physics*, having used them as an undergraduate physics student in the same environment that he is now a TA. This observation is consistent with Dancy and Henderson's finding that physics faculty who self-ascribe as users of a research-based curriculum may not necessarily implement them as designed [19], and when faculty modify research-based curricula, it tends to be in a way that emphasizes more traditional forms of teaching [20]. Opportunities to teach using transformed curricula afford a chance for graduate teachers to become deeply engaged with the aims of research-based instructional strategies that will serve them in future teaching; however, as

Daniel's example demonstrates, this engagement does not happen on its own.

Lastly, we should stress that we differentiate *coordination* of beliefs and practices from *inflexibility.* We view sophisticated teacher knowledge as inherently fluid and adaptive, and we therefore do not associate "sophistication" with any particular component of these dimensions. Rather, we expect more sophisticated instructional practices to be flexibly applied and informed by local contexts and student feedback.

4.4 Conclusions

In conclusion, we have developed a framework for the analysis of instructor beliefs and practices along three dimensions, which is grounded in both existing theory and emergent themes in the data drawn from interviews and observations of TAs. This TA-PIVOT framework serves to connect how TAs talk about their own teaching to the ways that they engage students in the classroom. In the process of constructing and applying the TA-PIVOT framework, we have observed *(1)* variation among TAs in their beliefs and practices, and *(2)* apparent instances of inconsistency between TAs' beliefs and practices. These apparent inconsistencies provide an opportunity to examine TAs' awareness and perception of how their classroom practices relate to their beliefs, and provide us as researchers the opportunity to investigate the nature and sources of tension between beliefs and practices.

We also note that the episodes described in this paper represent a "snapshot" in time, during which TA beliefs and practices may be in the process of changing. In the next chapter, we will address this issue by presenting an analysis of a broader set of TAs and tracking their beliefs and practices over the course of a semester. As a part of this follow-up study, we asked TAs in a post-semester interview to comment on video excerpts of themselves interacting with students in order to stimulate discussion and to inform our own interpretation of these episodes. We will describe how these structured self-reflections provided additional insight into how TAs themselves interpret classroom situations, as well as the types of constraints TAs face in enacting instructional practices that align with their intentions. Lastly we will examine in more detail comparisons between TA beliefs and practices, and discuss implications of this framework for TA preparation.

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Chapter 5

Examining Dynamics & Coordination of Beliefs and Practices Across Contexts

5.1 Introduction

In the previous chapter we documented the development and refinement of the TA-PIVOT framework for comparing both how TAs describe their own teaching, as well as the practices they use in the classroom. We observed evidence of both coordination and discoordination between beliefs and practices. However, this was a "snapshot" of one week which was unable to capture how TAs' beliefs and practices may change from week to week. In order to examine whether these same findings hold up over the course of a semester of teaching, we decided to apply this framework to a group of first-year graduate students serving as TAs in Physics 1110 during the Fall 2011 semester.

The research questions for this study are:

(1) Can we distinguish stated beliefs and practices for the expanded set of TAs?

(2) Can we observe differences in individual TAs' beliefs and practices across weeks? If so, is there evidence of consistent growth?

(3) What apparent consistencies and inconsistencies emerge between TAs' beliefs and practices?

5.1.1 Participants

The TAs serving in this course had a wide variety of prior teaching experiences, as presented in Table 5.1. None of these TAs were undergraduates at CU. "Darren" and "Joanna" had both

Table 5.1: Participants in expanded TA study. As before, pseudonyms have been used.

Participant	Gender	Prior teaching experience	Tutorial familiarity
Caleb	M	Former middle school mentor & college tutor	Low
Darren	M	Former undergrad Teaching Assistant & tutor	Low
Joanna	F	Former undergrad Teaching Assistant (in tutorials)	High
Terrence	M	Former Learning Assistant	Low
Oliver	M	None	Low

served as TAs as undergraduates, with Joanna having taught in a SCALE-UP [1] setting with the UW tutorials. "Terrence" served as a Learning Assistant as an undergraduate, although he decided not to participate in the accompanying pedagogy course because was busy preparing for the GRE and writing an undergraduate thesis. "Oliver" was an international graduate student who originally attended CU as part of an undergraduate research program, and was then accepted to the graduate program. In addition to serving as a college physics tutor, "Caleb" had also served as a K-8 reading tutor in a foreign country during college.

5.1.2 Structure

In order to characterize TA beliefs throughout the semester, we conducted pre-, mid-, and post-semester interviews using the same protocol in Appendix A. In parallel, we videotaped five weeks of the TAs' interaction with students (Week 4: Forces; Week 7: Work & Changes in Kinetic Energy; Week 9: Conservation of Momentum; Week 12: Conservation of Angular Momentum; and Week 14: Buoyancy). These recordings were conducted using the same fixed-camera methods described in Chapter 4. The complete layout of the study is shown in Fig. 5.1.

The first interviews took place after classes had started, so the TAs already had at least one week of teaching to draw upon. Furthermore, these interviews took place after each of the participants had completed the mandatory teaching orientation mentioned in Chapter 1. Hence, we do not claim that the first interviews reflect the TAs' initial "state" before entering the physics program. It was logistically difficult to arrange interviews with TAs before the orientation, and we were ultimately more interested in examining the ongoing impact of teaching in a transformed learning environment than the effect of a single workshop.

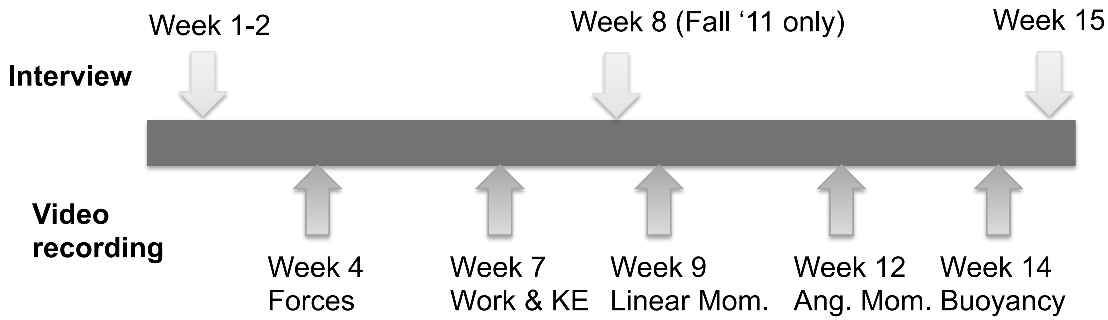

Figure 5.1: Structure of the Fall 2011 study.

5.2 Results

5.2.1 Beliefs

5.2.1.1 Variation in beliefs

In order to more easily distinguish between TAs over the course of the semester and represent changes in TA beliefs and practices, we have collapsed coding results along each subdimension by assigning a value to each code category and calculating a weighed average. Weights along each dimension were normalized to 1 so that each TA's mean fell between 0 and 1, with higher numbers generally corresponding to greater alignment with the curricular goals.

Table 5.2 shows how this was done for Agency.

Subcode	**Weight**	**# of codes**
Teacher	0	2
Mixed	0.5	10
Student	1	5
	Weighted average	0.588
	Std. deviation	0.318

Table 5.2: Example weighting of codes along the Agency dimension. Data is from Joanna's pre-semester interview.

The purpose of this strategy is to illustrate variation between TAs and track shifts rather than to place a value judgment on each TA. As discussed in the previous chapter, these dimensions correspond roughly with the goals of the curriculum rather than serving as an absolute "good/bad" scale of beliefs. Fig. 5.2 illustrates differences between TAs' coded beliefs in their first interview.

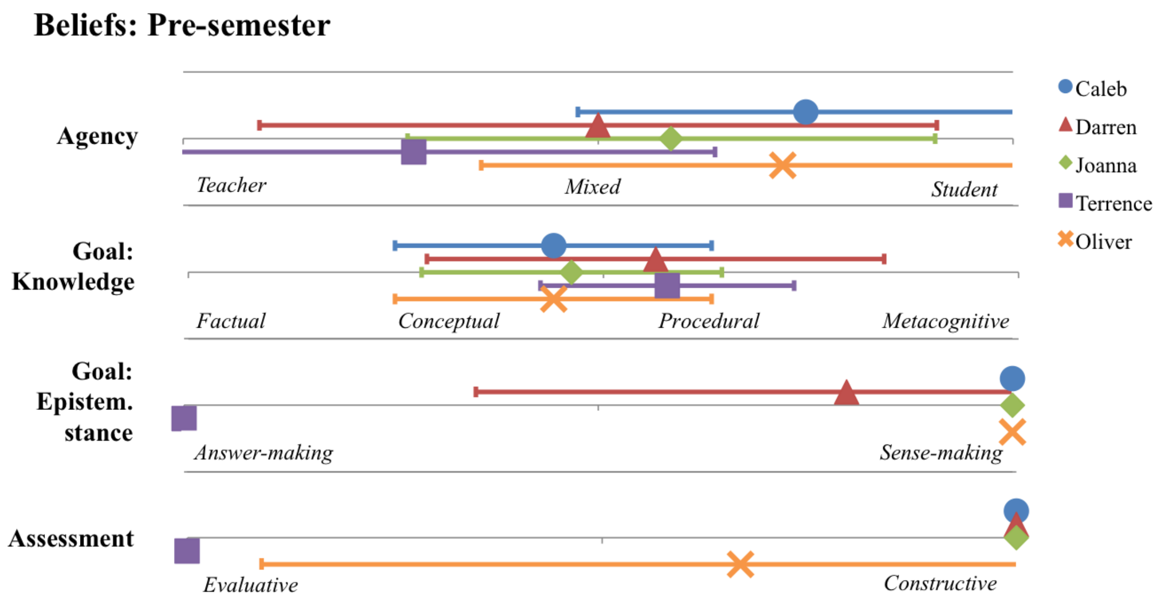

Figure 5.2: Collapsed representation of how TAs' coded beliefs compared for the first interview. (TA markers have been staggered vertically to make them easier to distinguish.)

As in Chapter 4, we will provide a description of each TA's pre-semester beliefs along each dimension accompanied by illustrative quotes, and summarize patterns at the end of the section before moving on to post-semester beliefs.

Agency

Of all the TAs, Caleb was coded as placing the strongest emphasis on *Student* agency in his first interview, as reflected by his commitment to hearing from multiple people and establishing consensus when working with groups of students. For example, Caleb described how he responded to student disagreement in a teaching situation:

> Oftentimes there's some disagreement between some of the students and so I say, "OK, you know, well what's your side and what's your side and why do you think

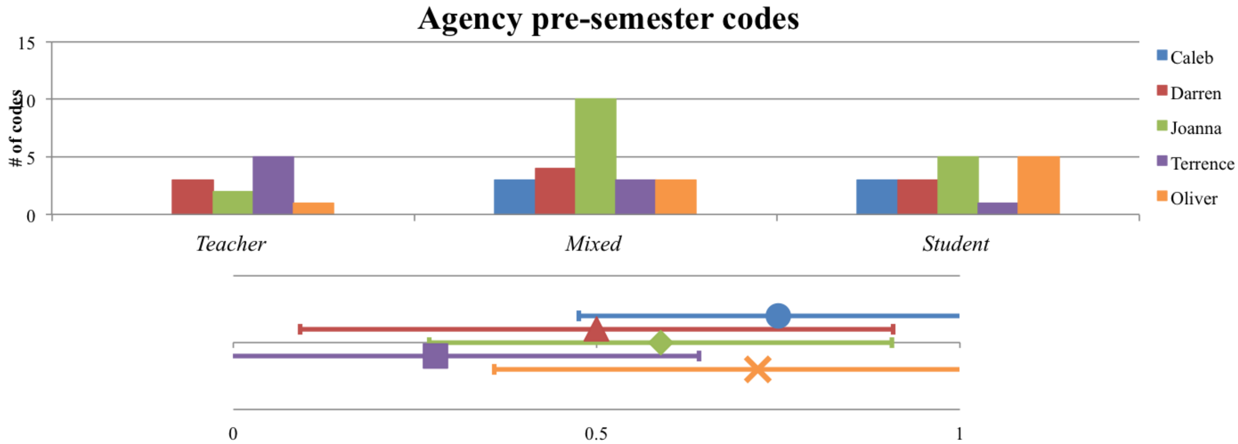

Figure 5.3: Illustration of pre-semester raw coding distribution for beliefs along the *Agency* dimension, as well as the corresponding collapsed representation.

> this, why do you think this," and they always say, "Well, which is right?" And I say, uh, you know, "You tell me!" You know, like which argument, you know, what do you guys think is more convincing? [Caleb pre, 00:18:35]

Here Caleb mentions hearing each student's position and their reasoning. Furthermore, when the students ask him for the correct answer, he responds by turning the question back on them and having the students convince him which conclusion is correct. Hence, even early on in the course, Caleb described how he attends not only to student collaboration (*Student agency*), but also to their *Sense-making*.

In contrast, Terrence was coded as valuing *Teacher* agency the most out of the five TAs. During his interview, Terrence talked about "attacking" student ideas, and students "sassing" him, which suggested a focus on his authority as an instructor. However, there was some attention to Student agency, in that Terrence took a clear stance that learning happens when students work through physics problems on their own:

> I guess [teaching is], you present some ideas, you wait for the students to write it down—and not understand it—and then you give them problems to go do so they can understand it, and then the teaching part is when they go do those problems and learn how to do it and understand it. You getting up in front of the class for an hour is not going to teach anybody anything. That's just, I don't believe that. [Terrence pre, 00:11:15]

Notably, Terrence identifies "the teaching part" as being when students are working through problems on their own, not when they are listening to a lecture. This was coded as valuing *Student* agency, but it represents a different take on *Student* agency than Caleb, in that Terrence does not go on to address collaboration between students.

Joanna was coded as being more mixed with respect to agency. In her first interview she described teaching as "a way of communicating the physics in a way that other people can understand." She described how good teaching is "not a one-way street" and requires "listening to your students" and taking on whatever role will help them learn the best.

> And sometimes like you just have to leave the student alone, even though you know they didn't get it, because they're not in a mood where they are able to learn and they're not open to it. So at that point I just, I try to give them all tools and then be like, "You should review this, please review this" and then leave them to their own devices. You can't like, force-feed knowledge. Unfortunately. It would be a lot easier to teach. [Joanna pre, 00:15:02]

Joanna's described approach emphasized individual student learning styles, and students developing independence as learners. She focused on encouraging students to discuss, but also gave some attention to her own authority and students being "sassy" toward her.

Darren was also coded as *Mixed* and had a fairly even distribution of codes between *Teacher*, *Student*, and *Mixed*. Darren summarized his view of teaching by describing it as "translating information," indicating a focus on both the content (language) to be learned and his own role as the translator:

> So I think teaching is like, trying to get people to visualize it in a way that's not as complicated so they understand it, and then like if they're really interested, they can keep moving on in the courses. But I think it's translating information at a level that everyone can understand. And I would think that's really hard to do. It takes a long time. But that's what I would say teaching is. [Darren pre, 00:17:11]

Darren's overall metaphor of teaching as translating information is not inherently *Teacher-* or *Student-centered*, although particular features of his description, such as sensitivity to student's level, were coded along this dimension. As we shall see, this was an explicit metaphor for teaching that Darren continued to use in each of his interviews.

Like Darren and Joanna, Oliver also focused on the "communication" aspect of teaching during his first interview:

> I think we talked about this in the workshops too, [teaching is] like transferring knowledge and also like, communicating a concept in some way, like y'know, making. . . I dunno. It's a hard question, I, just like, yeah I guess communicating something to some other person and making that other person acquire that knowledge. [Oliver pre, 00:14:05]

Here Oliver is explicit about students "acquiring" knowledge, which appears indicative of a focus on *Teacher* agency and *Answer-making*. Interestingly, Oliver describes this approach as having been discussed during the orientation workshop.

Goals

In describing shifts in the type of knowledge each TA tends to focus on, we encounter a challenge that the Bloom-like Knowledge categorization is not itself linear like the other dimensions. The original Bloom's Taxonomy of the cognitive domain was considered to be hierarchical; that is, mastery at a given level implied mastery at all lower levels [2]. We acknowledge that Anderson's condensed form of the Knowledge domain is not hierarchical in the same manner, and thus a linear organization may not be the best choice of representation for this dimension. We will continue to employ this representation in order to align with the other three dimensions, although we will show each TA's full set of data whenever possible in order to characterize their beliefs in a more complete manner.

The TAs were similar in their described content goals for students, which tended to emphasize a combination of *Conceptual* and *Procedural* knowledge. However, Terrence took a markedly different position than the other TAs in his epistemological stance. Here Terrence's initial description of what students should learn in an introductory physics course:

> I guess, they learn kinematics, force relationships, and gravity. Energy. Probably some pressure, maybe a little bit of like, in freshman, Bernoulli's principles and things like that. Uh, but mostly they need to learn how to set up differential equations. They don't even know they're differential equations yet, but at some

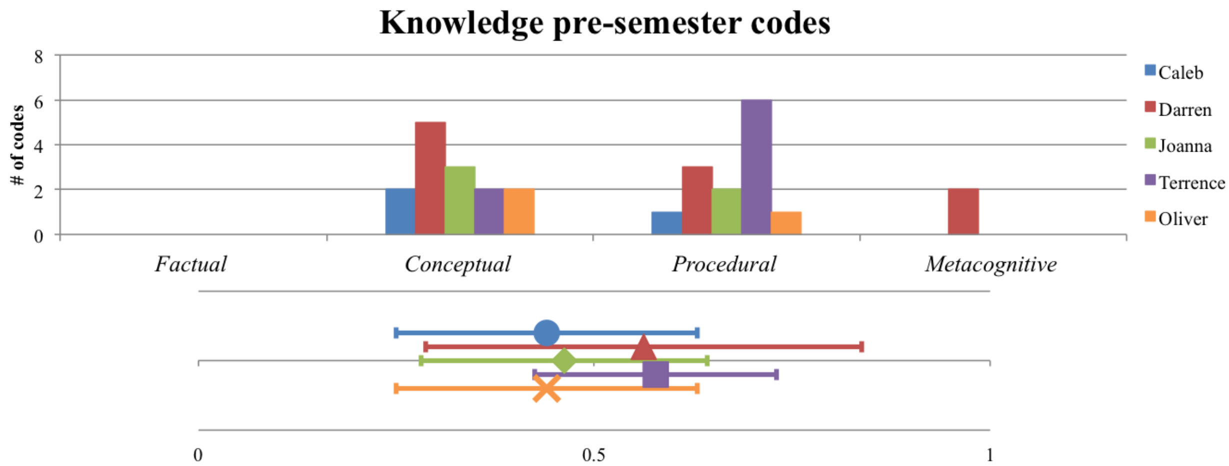

Figure 5.4: Illustration of pre-semester raw coding distribution for beliefs along the *Goal: Knowledge* dimension, as well as the corresponding collapsed representation.

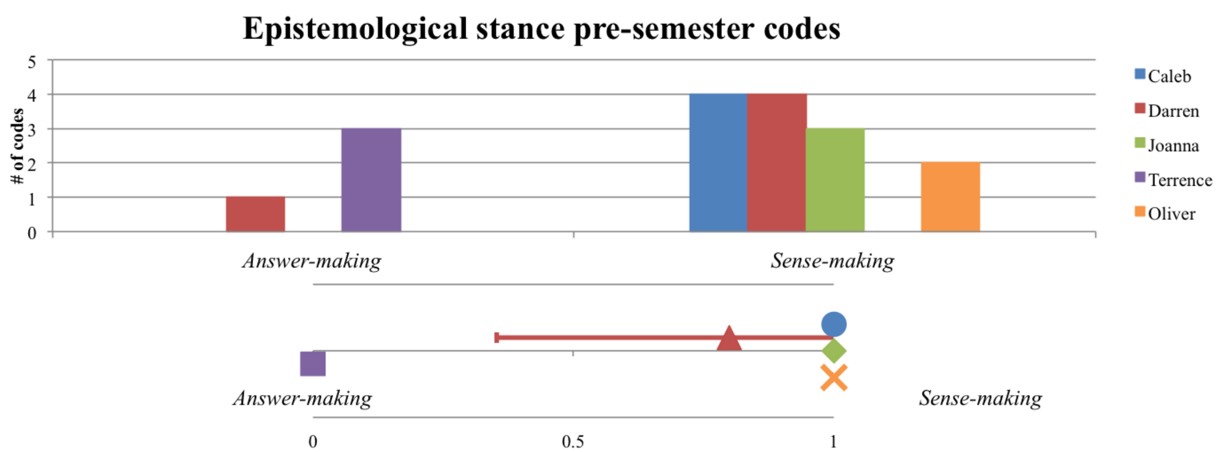

Figure 5.5: Illustration of pre-semester raw coding distribution for beliefs along the *Goal: Epistemological stance* dimension, as well as the corresponding collapsed representation.

> point they will learn that that's what they were doing. Because that's what they're going to be doing the rest of their career. So, um, they need to learn how to think about a system, break it down, and set up an equation to describe it. [Terrence pre, 00:13:05]

We see that Terrence is interested in the development of high-level mathematical formalisms (particularly differential equations, which are beyond the scope of Physics 1110). Notice also that Terrence describes how modeling physical situations with equations is what his students will be doing "the rest of their career."

Terrence's epistemological stance is best encapsulated by the quote, "I will go through every single step of the question with [the students] to make sure they got every single part right." This was coded as an explicit focus on *Answer-making*, which differed from the primarily *Sense-making* stance adopted by the other TAs.

Like Keith in the previous chapter, Darren spent the most time of these TAs talking about his goals for students. Here he discussed how students should learn to approach physics, in what he called a "new level of thinking":

> So like, and that's another thing, like I think after studying for the GRE, this is something that like I think physics students should get out, is that's like, so like, does this, does like, what you expect to happen happen if you change this variable this way? Like if the mass becomes essentially infinity, what happens? Or if it becomes really low, what happens? Like, it's all just different problem solving strategies that I think you should get out of physics class, in addition to like, mechanics, E&M, like those little topics in intro. [Terrence pre, 00:21:01]

Here Darren is emphasizing *Procedural* knowledge, but notably he attends to different strategies than some of the other TAs, such as considering limiting cases, and making predictions. We coded this as including an element of *Sense-making* as well. Darren talked about the importance of identifying the "big picture" when studying physics, and was the only TA to explicitly address *Metacognitive* knowledge in his pre-interview:

> Like, if you can figure it out that you were wrong yourself and why you were wrong, then you learn the material better. [Darren pre, 00:24:57]

In describing his role in the classroom during his first interview, Darren also mentioned where he wants students to end up:

> I would say that I am trying to guide them so they, like their ultimate goal is like, me not to teach them, for them to figure it out themselves. But I kind of guide them, like, along the way. [Darren pre, 00:17:45]

This quote represents an overlap between coding dimensions, as Darren views the development of student agency as a goal in its own right.

In a similar manner, Caleb's goals for students depend on their respective backgrounds and career interests:

> I know why *I* take physics, but why are all those kids taking physics? So I actually asked everyone that, you know, at the beginning of last Thursday, every class I asked them, you know, "How many of you guys are engineers? How many of you guys are here because you've got to take a science class? How many of you are doing pre-med requirements or actually want to study physics? Are there any mathematicians?" And uh, you know, far and away they are largely there doing engineering pre-reqs. So, you know, what do you need to know for engineering? Well, engineering is a lot about solving practical problems. You know? So engineering is a lot about the "how" and maybe not as much about the "why." [Caleb pre, 00:03:48]

Here Caleb acknowledges "solving practical problems" (*Procedural*) as a goal, but also understanding the "why" (*Conceptual*). Moreover, the fact that he is sensitive to the individual needs of students is further evidence of Caleb's attention to Student agency (particularly when contrasted with the more fixed approach to learning goals that Terrence described above).

Joanna's pre-semester goals in the classroom focused on students making sense of and being able to use mathematical tools such as formulas:

> . . . after having probed deeper into basic kinematics they were able to understand much better how to use the formulas and things. It was mostly students who were formula-based, who were like, "I don't have an equation, I don't know how to do this problem." And then you force them to think very critically about what do the equations mean, where they come from, and then they're able to use them better." [Joanna pre, 00:21:28]

This interplay between *Conceptual* and *Procedural* knowledge is similar to Sarah's perspective from the previous chapter. Furthermore, Joanna's emphasis on "what the equations mean" suggests an additional focus on *Sense-making*.

As seen earlier, Oliver described "acquiring knowledge" as an outcome of learning. However, in the same interview he also took a stance against the rote memorization of equations, which he compared to recalling dates in a history class:

> . . . in history it feels like there's more like fact-based, y'know, you want to memorize stuff, I guess, I mean, dates, stuff like that. In physics you need more, you need to learn the concepts and then you need to be able to apply them. [Oliver pre, 00:14:48]

In addition, Oliver views introductory courses as an opportunity for students to get a feel for the basic concepts in order to prepare them for "higher level physics."

Assessment

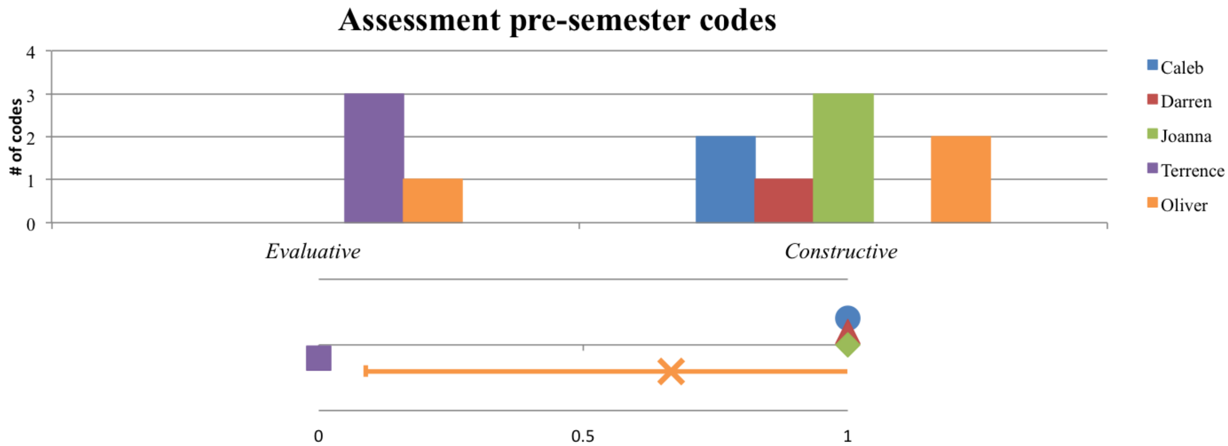

Figure 5.6: Illustration of pre-semester raw coding distribution for beliefs along the *Assessment* dimension, as well as the corresponding collapsed representation.

The TAs exhibited differences in how they assess student understanding. Terrence described how he likes to "attack" the students' answers and force them to defend their reasoning, which also informs him whether they completely understand or not, as illustrated here:

> Int: It sounds like, um, you like to ask them if they're sure about their answer, and if they're sure, then you—
>
> Terrence: "Would you bet money on it?" *(laughs)* "Are you *really* sure?"
>
> I: And then once they're, if they're—
>
> T: If they're really, really sure, say, "OK," then, "You're right" or "[You're] wrong." After they've explained it to me. And then say, "Sure." [Terrence pre, 00:21:20]

Terrence considers it important to put students on the spot, after which he tells them whether they're right or wrong and whether they may proceed through the tutorial (*Evaluative*). He describes using these verbal "quizzes" on students after they have completed the tutorial in order to decide whether they are actually "done" or not.

Joanna described how questioning can lead to student learning. In this quote, coded as *Constructive*, Joanna talks about how prompting a student to explain can help them overcome a difficulty they were facing:

> Usually when I first sit down with a student I ask them like how they tried to solve the problem and <u>why</u> they tried to solve it that way. And then you can kind of see where they're coming from, and then usually by asking them to explain it, a lot of the times they figure out what their issue was when they actually have to—when they have to talk through it. [Joanna pre, 00:13:11]

There are two particular features of assessment that Joanna mentions: it is informative for her as an instructor, and that the process of talking through their answer helps students self-correct.

In a similar manner, Caleb talked about homeworks and exams that he considers "really good":

> I think that a lot of the best, like "Aha" moments I've had, y'know, some of them have been in lectures. A lot of them have been on tests, y'know. When you write really good tests as a teacher, that's like, y'know if you write really good homework problems and really good tests, your kids are going to learn a lot, y'know? [Caleb pre, 00:09:47]

In this quote Caleb views traditionally summative forms of assessment, such as homework and exams, as potential avenues for learning (*Constructive*). This is a slightly different framing than Keith's description in the previous chapter of structuring a metacognitive activity following an exam, as the opportunity for learning is embedded in the form of assessment itself.

Oliver had the least to say about assessment, although he did comment that having students work in groups provides "kind of a check" on student understanding, as "you're forced to express your understanding in words." He also mentions the Socratic method as being important, but says that he finds it challenging and needs practice with it.

5.2.1.2 Dynamics in beliefs

Before moving on to practices, we will first discuss changes in TAs' stated beliefs over the course of the semester. In Fig. 5.7 we present coded data from the final interview along with indications of how each TA changed relative to their first interview. In this section we highlight and comment on particular trends using illustrative quotes.

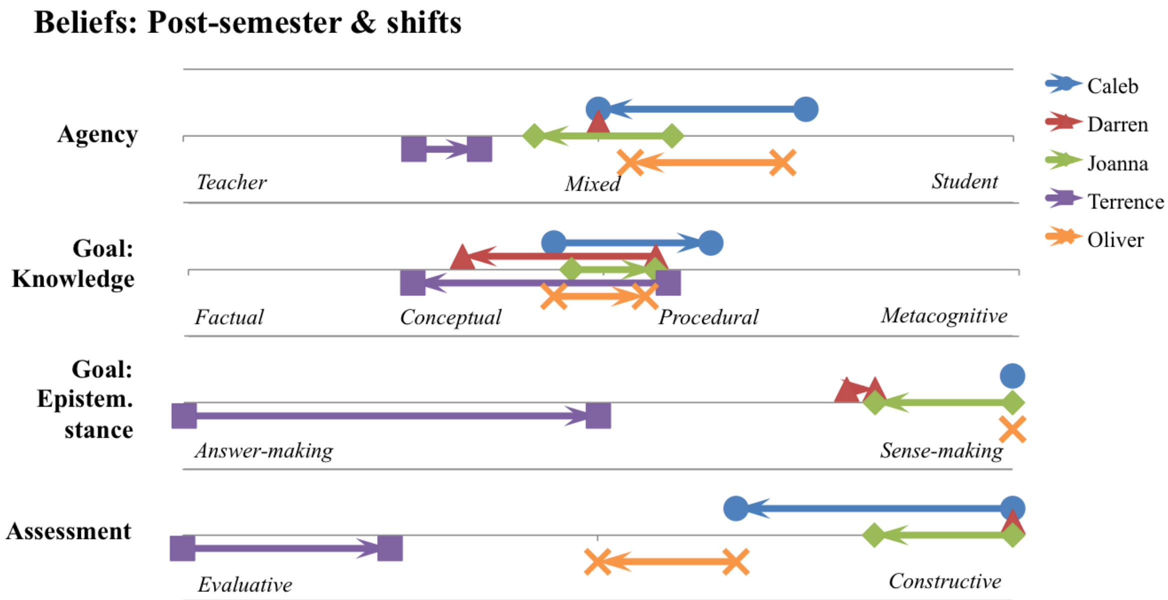

Figure 5.7: Shifts in coded TA beliefs along the TA-PIVOT dimensions between pre- and post-interviews. Horizontal arrows point from pre to post; TA markers without an arrow had the same aggregate result between pre and post. (TA markers have been staggered vertically to make them easier to distinguish.)

Caleb

Although Caleb mentioned the importance of student collaboration in his final interview, it did not feature as prominently as it had at the beginning of the semester. Instead, he tended to emphasize the importance of the relationship formed between himself and the individual students. In particular, Caleb talked about how he tried to communicate respect for students, specifically to "treat them like [he] would treat coworkers":

> Just because I think that that really, y'know, when you're actually talking to someone and they feel like you care what they think and so then they are more likely to participate and so, in that sense, I really do try to build a rapport with the kids and, y'know, if you have a relationship with someone, it's always easier to work with them. [Caleb post, 00:38:52]

Caleb also expressed a goal for students to make sense of physics they experience outside the classroom, even long after they leave college:

> What I really hope they do is try to explain the things they see in their life with like, the stuff that we learn... Maybe their kid says, "Why does the wall push me, y'know, out, or something when I—you know, why do I fly out when we go around a turn in the car?" And that, y'know, maybe they haven't, maybe then they can be like, "Oh, well, it's actually that the car is accelerating inward, and you're not attached to the car, so..." [Caleb post, 00:09:24]

Additionally, Caleb described how he can tell students really understand when they are able to reconstruct an argument themselves rather than simply recognizing the result:

> When they can explain it to you with a blank piece of paper, that is a pretty good... that's kinda how I when I can really do something. [Caleb post, 00:16:16]

The approach to assessment Caleb describes here focuses on students' ability to construct an argument (*Sense-making*) rather than the final result. He also expressed frustration with homework grades not really reflecting student understanding, and speculated that having shorter assignments more frequently would be a better system.

A notable instance of *Constructive* assessment came from Caleb recalling a CAPA problem that impressed students with the elegance of its result:

> ...there was another CAPA problem where they measure the [period] of a satellite in near-surface orbit around a planet... And then they have to calculate the density of the planet. Y'know, this is a very nice problem, I think, and a ton of the kids in help room asked about it... when we would talk about how to solve it I would try to always emphasize at the end, y'know, what we had done, which is, you know, think about this—you know, this is a planet. We can't put it on a scale, y'know, we can't hold a ruler up to it. But we can sit with a satellite and watch something circle around it and just by doing that we can—sorry, sit with a telescope—and watch a satellite circle around it. And just by doing that we can figure out the ratio of this mass to volume. It's pretty amazing. Y'know, I think a lot of them were like, "Oh yeah, that is, wow, we are kind of really getting away with something there, y'know." [Caleb post, 00:07:09]

This quote indicates how Caleb uses a traditionally summative form of assessment, an online homework problem, to help students develop a greater appreciation for an "amazing" conceptual aspect of gravitation.

Darren

Darren reiterated his teaching as translating metaphor throughout the semester, including during his final interview:

> Because like, [teaching] is translating. Like, it's still translating like [for me] today. Like, I mean, in Jackson or whatever, I don't know what the stuff is. But y'know, the teacher simplifies it and tells us how to do it in his own way and now I understand it more, so if I want to go back and read the Jackson book, y'know, I can understand it now. So it's taking stuff—it's taking information and just putting it on their own level so that they understand it. [Darren post, 00:09:15]

Again, Darren's focus is on the teacher taking information and communicating it in a way a student can understand, but applies it to the context of his own learning.

Darren wants students to understand that "we can describe the universe using mathematics," but also emphasizes that anyone can learn it:

> And so I would try to [give] the message that, you can do this, it's not this impossible feat to learn physics. [Darren post, 00:14:34]

Darren did not change very much in his stated beliefs regarding Assessment, although it was not a focal component of his beliefs in either interview.

> Usually like, people—it's weird—people have different react—like, they'll act differently when they understand it. Like they'll act, uh, when everything's under control, you can just tell, like I can just sense it, like they'll be like laughing, like people actually are laughing in tutorial class? Like, that's usually a good sign. [Darren post, 00:21:58]

Here Darren describes how he can "sense" when students understand based on changes in their behaviors, such as laughter, which we coded as a *Situated* approach to assessment.

Joanna

Joanna's discussion of her role in the classroom took on a different character than earlier in the semester. In particular, she spent a long time discussing the tension she felt between her need to control her class and her ability to be friendly with students:

> And now to be in a situation where I am like the authority figure, kind of a thing, made it more difficult to find a line where I could still be very like colloquial and genial with the students without them trying to take advantage of me for it... And I definitely tried to keep them feeling like I wasn't such a big scary teacher, kind of a thing. But at the same time it became very frustrating for students who refused to acknowledge that I was [like] a professor and were, like, disrespectful and stuff. [Joanna post, 00:38:02]

This increased attention to her authority in the classroom, which we coded as emphasizing Teacher agency, resulted in a shift toward mixed Agency. Nonetheless, Joanna did attend to Student agency in her final interview:

> Teaching, at least physics, for me is like teaching students how to teach themselves, a lot of it. It's giving them the tools that they need to then be self-sufficient. My ultimate goal as like a teacher of physics would be for them to not need me anymore. That would be awesome. [Joanna post, 00:30:10]

Joanna had the smallest observed shift in knowledge beliefs out of the five TAs, which also placed her between *Conceptual* and *Procedural* knowledge. It is worth noting that she also emphasized *Metacognitive* knowledge during her final interview, as part of a comment on the tutorial approach:

> I think also a lot of students don't realize that the tutorials are self-correcting like that. I think there are like, maybe like half the students didn't realize that the end chunk of the tutorial is designed to ask questions to make you rethink what you did previously. And I think almost if we had like a little info session about how the tutorials do that, it would really help students. [Joanna post, 00:06:01]

Here we see Joanna focusing on the "self-correcting" aspect of the tutorials, as a way of structuring the metacognitive act of rethinking previous ideas. Joanna was one of the only TAs in the study to attend to this feature of the *Tutorials*, which is perhaps not surprising given her prior experience and familiarity with the tutorial model.

Terrence

As in his first interview, Terrence said that students should leave the course "knowing that the derivative of velocity is acceleration" (*Factual*). However, he added to this a *Conceptual* component that students should have an understand physical phenomena

> Um, and I guess they should have some understanding of how, conceptually, how physics works. "Well, why doesn't the Earth fall into the Sun?"—That would be something they should leave knowing. *(laughs)* Right? They don't have to necessarily be able to calculate it, but they should understand why we're not falling into the Sun. [Terrence post, 00:15:28]

In addition, Terrence explicitly rejected the memorization of physics ideas in favor of "critical thinking":

> I think a lot of people come into physics with the mentality that's taught in high schools, [which is] that you're supposed to memorize facts and then come back, and that's not what physics is about at all. And they have to develop critical thinking that they haven't had to develop. [Terrence post, 00:18:10]

Interestingly, although his statements regarding Agency were fairly similar to ones he expressed earlier in the semester, only during his final interview did Terrence specifically use the terms "active" and "passive" learning:

> So in my opinion if you're gonna have kind of these sessions, the teaching is supposed to be forcing the student to be an active learner, as opposed to a passive learner. So you have to force the student to answer questions and force them to think. 'Cause that's the only real way that you can teach somebody something, I think. Unless— there's two ways of learning, in my mind. Either you force them to be an active learner, or they learn it themselves. And so, basically my job is to make them actively think about the physics, is how I see it. As opposed to me telling them physics. [Terrence post, 00:17:07]

Throughout the interview, Terrence used homework scores to describe who his "best" students were. Later, he characterized a student as the smartest one at his table, "based on his homeworks." We coded this reliance on grades and scores to distinguish students as a further reliance on *Evaluative* forms of assessment.

Oliver

Oliver's perspective on Agency is very similar to the one he expressed at the beginning of the semester, although he tended more toward emphasizing Mixed approaches such as motivating students. In this quote he describes how he avoids trying to be the "teacher on a pedestal":

> I try to act not super secure about it, I think, I guess. Not be, as I said before, not be the guy who just like comes to their table and [is] like, "So this is how it is, so this is how it is, so like. . . " More like, I try to look like I have to think more than I actually have to think. 'Cause like, yeah, put myself in their position, like, so how should we think about this? [Oliver post, 00:42:27]

This quote provides a contrast to Daniel's belief that the TA should know the material "cold" to avoid being caught off-guard (Chapter 4). In particular, Oliver describes not wanting to present himself to students as an all-knowing expert. However, later in the interview he expressed regret over an instance in which he felt he acted too uncertain in response to an unexpected outcome with a demonstration during class. Hence there appears to be a "range" of authority that Oliver feels comfortable occupying as an instructor. Oliver also described how his ability to approach tables is still something that he is working on and would like to improve.

5.2.1.3 Summary

In order to visualize shifts in TA beliefs alongside variation in coding results, we introduce a 2-D representation that uses the pre/post belief coding data as X-Y coordinates, as shown in Fig. 5.8. This representation allows the span of codes to be visualized through conventional error bars, while the X-Y position indicates the pre-post shift (if any) in the TAs coded beliefs. Points along the X-Y axis are indicative of no pre-post shift in beliefs, whereas points above or below the diagonal indicate shifts that are aligned or anti-aligned with the curricular approach. Furthermore, the distance between the point and the diagonal indicates the size of the shift.

As seen in Fig. 5.9, the TAs appeared more mixed around the constructs of Agency and Knowledge goals than the other dimensions. Terrence appeared to undergo large shifts along Epistemological Stance and Assessment, but these may be exaggerated due to the small number of overall codes compared to other dimensions. The TA who appeared to undergo the smallest shifts was Darren, who we already noted was very consistent in using a particular metaphor for his teaching.

In the next section, we extend the framework to consider the practices used by the 5 TAs

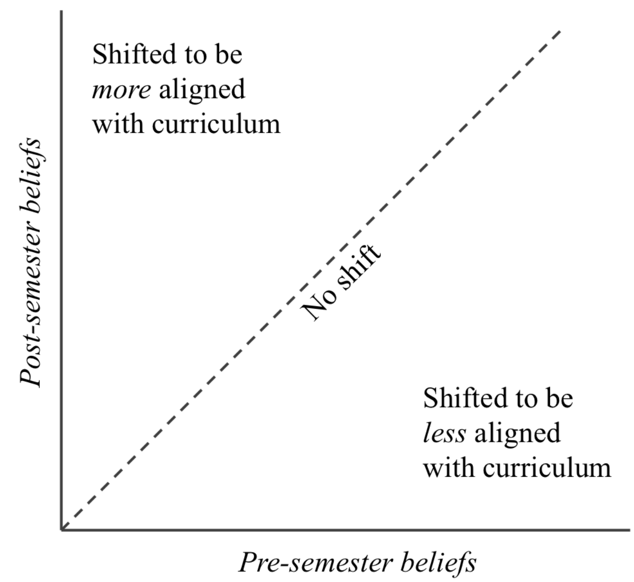

Figure 5.8: How to interpret 2D plot of post- versus pre-semester beliefs.

during Fall 2011. In order to get a sense of the overall span of the semester, we will focus on providing descriptive detail for Weeks 4, 9, and 14. For each week, we present results of coding data, followed by discussions of teaching excerpts of from that week to illustrate aspects of each TA's practice.

5.2.2 Practices

5.2.2.1 Week 4

As before, we will begin by illustrating differences between TA practices during the first videotaped tutorial from Week 4, "Forces".

Caleb

The following excerpt is from Week 4, the "Forces" tutorial. In this episode, Caleb is working with four students, labeled S1-4. The students are discussing the free-body diagrams for two books stacked on a table.

Caleb: Alright, so where are we in the tutorial? Let's talk about that.

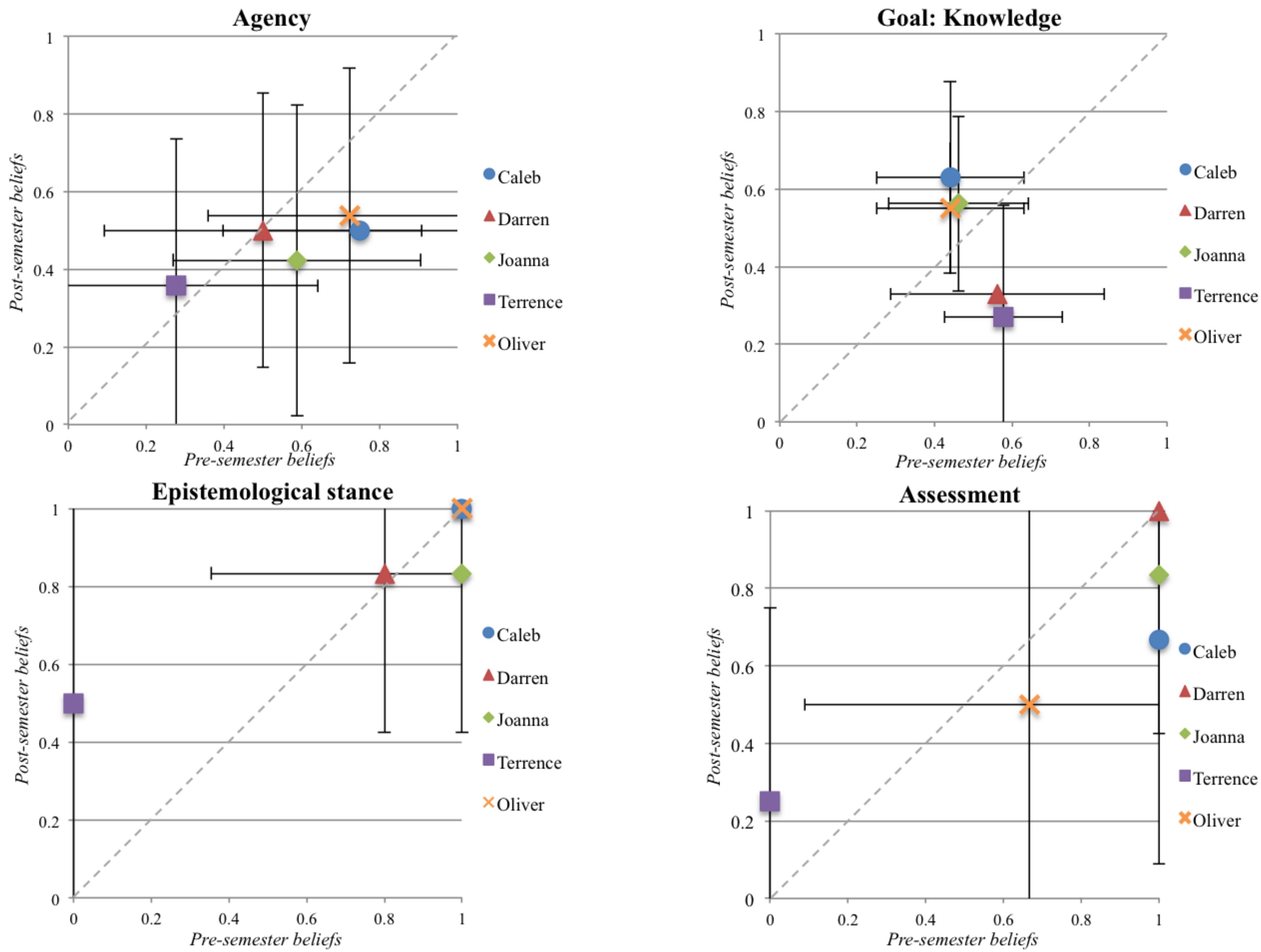

Figure 5.9: 2D plot of TA post- versus pre-semester beliefs.

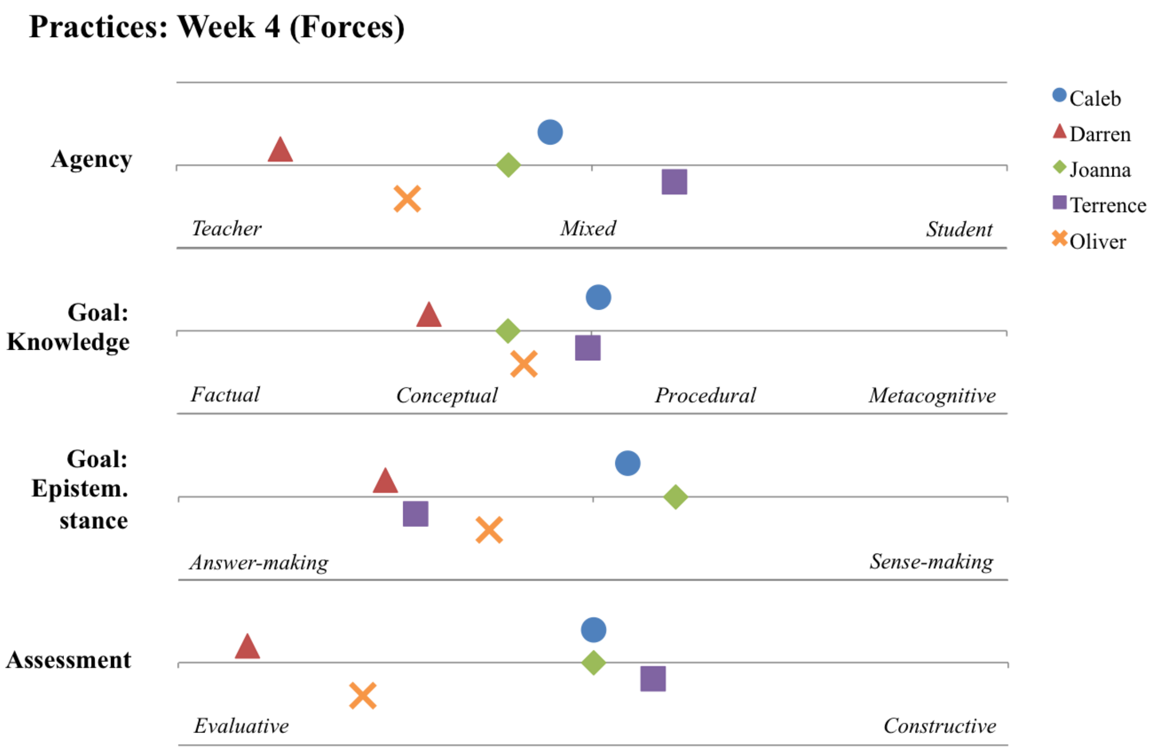

Figure 5.10: Collapsed representation of how TAs compared in their coded practices during Week 4.

S4: Basically the top book only interacts with one object in space, therefore it has a normal force and a gravity force, [which] better be equal and [in] opposite directions. The bottom book has three forces acting on it: one force being its own weight, the force of the top book acting on it, and then the normal force from the table.

S3 (to S4): Would those two be equal?

S4: These two don't have to be equal, but these two add together.

S3: Yeah, so, F plus mg equals F_N. Because it's not moving.

C: So, [S1], does this make sense to you?

S1: Yeah.

C: Cool.

C: [S2], how about you?

S2: Yep.

C: On board. Cool.

C: Can we all look at our free-body diagrams really quickly? Just so I can make sure that you guys…OK, so we're all in agreement. *[looking at students' tutorial books]* Are we all in agreement?

C: Alright, looks like we are…pretty consistent. Cool.

C: Uh, I do think it's really good to be explicit about what the force is on and what the force is by. I encourage you guys to do that. I know it's kind of annoying.

S3: So this would be like force from table on book, the normal force going up, would be force from table on book?

C: So that's a really good point. Now that we're being explicit about this, what actually is causing that normal force? What do you think, [S3]?

S3: I thought it was the table. Force on the book by the table.

C: OK. [S1]?

S1: Table pushing up.

C: [S2]?

S2: I'd agree. Book by table.

C: Consensus. Cool. I will also vote that.

S4: OK.

C: So force on book by table.

S2: So then we would just say for—gravity—

C: How about the other normal forces in this picture? How would we write the vector for that?

S?: Force of upper book on the lower book?

C: Cool.

In this episode, Caleb starts by orienting the group toward the task of discussing the tutorial content. In Lines 10 and 13, he asks individual students by name whether the discussion makes sense to them. In line 25, he acknowledges S3's question ("that's a really good point"), but instead of directly answering it, he redirects the question to the table and goes around to ask each student individually by name. Only after each student has expressed an opinion does he weigh in (Line 32). This step of establishing consensus and addressing students by name was common for Caleb. In this clip, we observe multiple levels of Agency being emphasized: the TA orienting the group toward a task (*Teacher*), checking with students (*Mixed*), and establishing group consensus (*Student*). We also note that each student is heard from at least once during the interaction.

This episode exhibits a mix of *Conceptual* (Newton's Third Law) and *Procedural* (use of subscripts) knowledge. Although Caleb did not attend to student reasoning in this episode, he did so during other episodes from this week.

Darren

Darren's practices were coded as being more Teacher-centered than Caleb's. To see how this was reflected in action, consider the following Week 4 episode in which Darren works with a group of four students on the same "stacked book" free-body diagram.

Darren: OK, so how are you guys doing over here?

S1: (turning book toward TA) Um, getting to...

D: OK, so let's talk about some stuff first. Um, so let's...so does everyone understand the difference between contact and non-contact forces?

[some nods and "yes"es]

D: OK, so that's very important to have that distinction and stuff, but if you understand it that's good.

D: Um, so now question E has these students discussing some scenarios. Does anyone agree with any of them, does anyone disagree with any of them?

S4: We kind of decided that [student] 2 is sorta right, but since Pam is exerting the same force on the rope that the rope's exerting on the block, they're the same?

D: Yeah, they're the same exact force.

S4: Is that true?

D: You're right, you guys are right.

D: Um, so now page number 2. Someone explain to me their free-body diagram for this book resting on the table.

S2: I think the normal force and the force of gravity would be equal, since the book isn't moving.

D: Yep, and that's very—you have to make a distinction, like as we were talking about earlier. These vectors have to be the same together.

S2: They have to be the same length.

S4: Is there a way to like, know what the magnitudes of these [forces] are for this diagram, or is it essentially just make up–

D: No, you gotta—Yeah, you would have to um... you would actually have to know the mass of the book. Yeah, but that's a good question. But vectorially they would have to be, um... *[leans down to look at book]*

D: OK, so I'll let you guys start this one, 'cause this is like another 4 questions.

In this episode we observe similar instances of Darren orienting the group toward specific sections of the tutorial, but in contrast to Caleb there are no instances of Darren encouraging group engagement or discussion. Additionally, Darren consistently answers student questions directly, without turning them back toward the group or using them to set up subsequent discussion. Consequently, almost the entirety of the discussion is oriented toward the TA, with little to no interaction between students. We also see Darren place verbal emphasis on points that he considers "very important" to know.

Joanna

Joanna was coded as *Mixed* in her practices along Agency during Week 4. Consider the following episode in which students draw and label a free-body diagram of two people exerting forces on a stationary block:

[Joanna looks at S1 & S4's books]

Joanna: Do you guys all agree on part E?

S4: We disagreed with student 2 [unclear] Pam isn't exerting a force on the block because she's pulling on the rope, which is pulling on the block.

J: Anybody disagree with that?

S1: Well at first we said force of Pam, but you know, it's wrong.

S2: It's the rope pulling.

S3: But then what's causing the force of the rope?

J: Does it matter?

S2: Not really. It just matters that there is a force.

S3: Because anything could be pulling on the rope, not just Pam.

J: It could be a whale! A truck, anything.

S3: But OK, it's the force of the rope plus the force of Chris.

J: I wouldn't draw those added together, I'd draw them as two separate forces. They're still distinct, and they're even different types of forces. The rope is a tension force, and what type of force is Chris exerting?

S3: Perpendicular.

S1: Force of C. Force of Chris. *[Gestures uncertainly]*

J: What kind of a force is he exerting?

S4: Normal force.

J: Normal force. You guys get why it's a normal force?

S2: It's perpendicular to the block?

J: Yeah. I also think of it—anytime you're wondering why two things just aren't going through each other, like why Chris isn't falling into the block, it's a normal force.

S3: OK, so what is the force the block is exerting on Chris? Is that a normal force as well?

J: [Nods]

S3: OK. They're both normal forces.

J: Yeah.

Here Joanna prompts for disagreement within the group (Line 5), a form of positioning that was coded as valuing Student agency and Constructive questioning. Although she never switches into straight lecturing, Joanna does make suggestions at various points (Lines 14 % 23) about forces and free-body diagrams. Early in the semester Joanna also a demonstrated a "checking" mode that consisted primarily of brief I-R-E style questioning, as seen here during Week 7:

Joanna: Do you mind if I just look at your first page really quick?

[Looks at S4's tutorial book]

J: So for part C, do you guys all have the same thing for that?

S3: Same direction if it's positive, opposite direction it's negative.

J: How about the case up here for part 2? A2?

S1: Perpendicular.

J: Right. So which component of the force then is really important?

S2: Horizontal.

J: In this case it's the horizontal. What if this were to be vertical? What if the block was being moved up?

S3: Vertical. So it's the parallel force.

J: Right. It's the component of the force parallel to the displacement that really contributes to work. So that's for that third part, C. You guys had the direction and the positives/negatives right. Also magnitude.

S1: So when it is perpendicular, what do you use?

J: So if I'm like, lifting up my book. *[Lifts tutorial book]* I'm exerting a force on it, and there's a displacement. So which, what sign is my work if I'm doing this?

S1: [Unclear]

J: Well, I'm talking about the motion from when I'm raising my book. (pause) Which direction is my force?

S1: [Points up]

J: Which direction is my displacement?

S1: [Points up] So it's…

J: Right. The, [unclear] part asks about pushing at, like if I'm trying to move my book across the table I'm pushing down at an angle like in this first part here. Then only some component of my force actually contributes to the work.

This interaction is very similar to Sarah's "checking" mode described in the previous chapter, including the way that Joanna first asks permission to go over a previous page before interacting.

Terrence

Terrence's instructional approach is illustrated in the following Week 4 episode, again featuring the "stacked book" problem.

[Terrence sits down with group]

S2: But so that it doesn't go down, this book has to exert the same— has to y'know, uh…

S1: To push back the same amount.

S3: Yeah.

S1: But when you draw that up, y'know, you put another line down here and that's the natural force on that lower book, right. So then you have another one of those match it.

S2: So basically this one equals this one.

S1: What if this book weighs more, though? Doesn't it make that larger?

S2: No, if it weighs more, even this goes larger. It's the weight. So if it is larger, it has more weight too.

S3: So the normal force will correlate you see, increasing in the same way.

S2: OK.

Terrence: You guys wanna explain that to me?

S1: Here, let me try to explain it. Um, so. This is kind of how we were going about it. You've got the book and the first one. So it's got the normal force and the weight.

T: Part 1, OK.

S1: Part 2. And we're talking about the book on the bottom. So you've got the weight of the book itself, right? And then you've got the normal force from the book on top, right? And then you have the normal force pushing back up. It's gotta be the same magnitude as these two forces coming down.

T: So why do you label this one F normal and draw this normal where you labeled F and you list this one normal but you never put it in?

S1: I've got a bad habit of writing F instead of...

T: OK. We should use subscripts, right? So we know what we're talking about.

S1: Alright, this is a normal force on the book by the table. And this is the weight of the book by gravity. And this is the normal force from book 1 to book 2.

T: So why's it a normal force?

S1: 'Cause it's pushing down.

T: Well isn't gravity pushing down?

S1: Well gravity...
S2: Gravity's pulling down the upper one. Gravity's not pushing down the lower one. Gravity's pulling down the upper one, and in turn the upper one is pushing that same force on the lower book.
S3: Basically these 2 books are in contact, and contact force is a normal force. So you wouldn't label two gravity forces, there's only one gravity acting on the little one. And then you have two contact forces, so it's normal.
T: Let me ask you guys a different question. Did you guys label two gravity forces the first time you looked at this one?
S3: No.
T: No, you did two normal forces. That's good. So let me ask a different question. If you had labeled two gravity forces, how would you know immediately that was wrong?
S2: Because they're in contact.
T: Even more basic.
S3: 'Cause there's no two gravitys acting on it. This one only has one gravity.
T: Gravity can only act on an object once, right? Cool. Good, guys.

This episode exemplifies a few features of Terrence's approach. First, he sits silently at the table for a while without interrupting the conversation that S1 and S2 are having. He also uses very brief questions to challenge student thinking (Line 31) but also to probe understanding. Like the other TAs during this week, Terrence also attends to *Procedural* knowledge, such as the use of subscripts (Line 27).

Oliver

Oliver's discussions with students tended to be brief in comparison to the other TAs. He often spent less than two minutes per interaction, which was consistent throughout the semester.

In the following excerpt, Oliver goes over a group's free-body diagram after the tutorial prompts them to have an instructor check their work.

Oliver: You have a question?

S3: Uh, they wanted you to come check our free body diagram.

O: Oh, they want that? I guess I'll have to do that.

[leans down to look at big sheet of paper]

O: So... OK, we've got F_{Pam}, F_{Chris}. So you draw them equal there. Do they have to be equal?

S2: Not necessarily.

S1: But it didn't specifically say they weren't equal.

O: (laughs) That's true. Yeah, I guess, simplify. Although sometimes, when you draw physics diagrams, it's dangerous to draw stuff equal that doesn't have to be equal. Because then you can be led to some false assumptions and stuff. But yeah, in this case, it's not that important. Uh, so let's see, can I see the first page? I need to refresh—"Describe the remaining forces." OK, so it's the normal force, so how does the normal force work. It works, like, if you drew it like, uh—

S2: Perpendicular to the surface.

O: And it's on the what by the what?

S?: *[Cross-talk]*On the block by the floor.

O: [Nods] Sounds good. And the gravity is...

S3: On the block by the Earth.

O: OK. And uh, what about F_{Pam}?

S3: We kind of changed F_{Pam} to tension force.

O: Ahhh. OK. That's pretty good. Why do you think that?

S3: Because Pam's exerting a force on the rope, and the rope is what is doing the force on the block.

O: Ah, OK. That sounds pretty good. So do you see the pattern here, like all the forces you drew for the block diagram are forces that are on the block. Like when you draw these force diagrams, free body diagrams, you only want to draw forces that are exerted on the block by other objects. *[Flips page in S4's book]* What was the second page? *[long pause while O reads]* OK, so you were right for the tension thing. That's good.

(pause)

O: (shrugs) OK, yeah, looks good.

Here we see Oliver use primarily closed-form questioning ("... it's on the what by the what?"), but he also attends to student reasoning ("Why do you think that?"). There are also a few examples of extended explanations regarding how the students should draw forces on their free-body diagram (Procedural). Overall, in this episode Oliver focuses primarily on what the students have written down and drawn to assess their correctness.

5.2.2.2 Week 9

The Week 9 tutorial was "Conservation of Momentum."

Darren

In this episode, Darren reviews the first page of the tutorial, which asks to find the net momentum of a system of two boats traveling in opposite directions with respective momenta of 25 kg m/s and 30 kg m/s.

Darren: You guys finished with page 1?

S5: Yeah.

S4: Uh-huh.

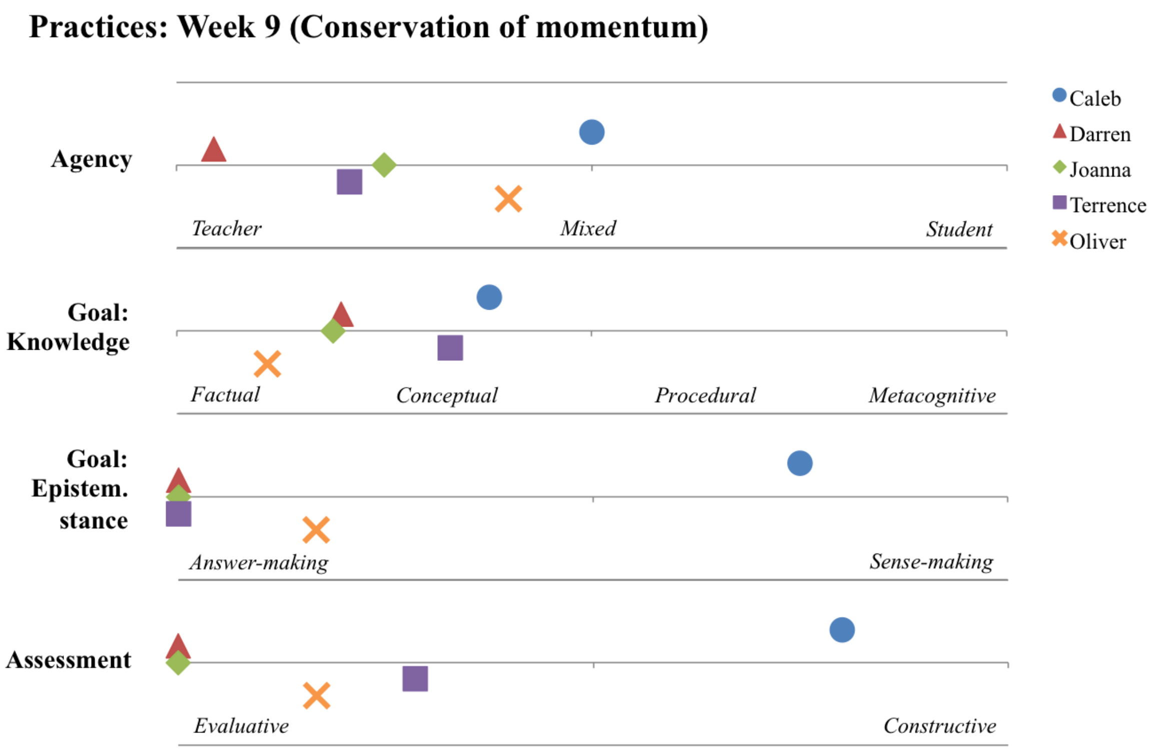

Figure 5.11: Collapsed representation of how TAs compared in their coded practices during Week 9.

D: Let's go back real quick. So I see a couple—is everyone working together, 'cause I see like people have all different—actually everyone has a different answer.

S5: For what?

D: Well you guys have 5—for number 2. Um, you guys have 5 kg m/s west, you [S2] have east, and you [S4] have. . .

S2: Oh, I meant to put west.

S4: Right and left, I'll just put east.

D: That's alright. So remember, what is—is momentum a vector or a scalar quantity?

S4: Vector.

D: It's a vector quantity, right? So how can I figure out the total momentum?

S5: Use vector addition.

D: Yeah, so use vector addition. So do you see why it's west? I mean, um... It might be better, I know like you can say west and east, it might be better just to keep it as like, west is negative so negative 30, plus 25 will give you minus 5 kg m/s. Because like, west is like assumed that like, east in the positive direction, like if you say negative 5, like anyone, any physicist is gonna know exactly what you mean by that. Um. Which, saying west is OK. But make sure you just define everything appropriately.

D: (to S4) Do you see why, um, OK, so remember. Look at the signs of each. Left, so, remember, just do mass times velocity. Don't do mass times speed. Like, try not to do the west-east thing. Mass 3 times <u>negative</u>, or mass 10 times <u>negative</u> 3 m/s. 'Cause remember, it's moving in the opposite direction.

S4: Yeah, so it's negative.

D: Yeah, so do you see, that might make it easier to see if you sum them. *[pointing to S4's book]* And remember it would be negative, it would be negative 5, right. Because this would be negative 30 plus 25. Just think of like, you have a vector of minus 30 and a vector of plus 25. Right? Um, here real quick. I don't wanna– I'm not trying to harp in any way. *[pointing to S4's book]* OK, so you have minus 30 for this one, right. And you have 25 for this one.

S4: So I have minus 5 total, right?

D: Yes, but um, I think this looks a little confusing. All you gotta say is, just minus 30 plus 25. I know like that's what that says here, but it's written a little—

S4: (laughs)

D: That might like, be confusing later. You know what I mean? Just literally, it's OK just to put minus 30 plus 25. 'Cause that's all you were doing, right.

S4: Just, OK.

D: Does that make sense? Does everyone see why it's minus 5, or 5 to the west?

[Various "yeah"s and nods]

D: OK, so like the main point, do you [S3] see what I mean, 'cause I see you showed up [unclear] late.

S3: Yeah, I just got through it. Yeah, it makes sense.

D: OK. Alright, I would recommend, unless you learned in class about the east and west, did you guys learn about that in class, or? I would like just say, we have a coordinate system here, and this is like negative x and this is positive. Like, that's gonna help out a lot later. 'Cause I think it's easy to make a mistake trying to keep east-west straight, rather than negative-positive. So, is everyone OK with page 1? So like, just remember the main point of page 1 is momentum is a vector. *[Chops hands with words]* Vector, vector, vector. So. Any questions?

[Various "Nope. Nope."]

Darren's instruction in this and other episodes during Week 9 was coded as highly Teacher-centered with respect to Agency. Darren spends most of this episode individually checking each student's tutorial book and giving explicit direction on how to respond and which concepts to focus on. Note in Line 51 how Darren physically chops the air as he repeats "vector," to provide added emphasis to this idea.

Darren's focus in this episode is on *Factual* knowledge ("Is momentum a vector or scalar quantity?"), but also *Procedural* knowledge involving the choice of coordinate system. We coded multiple instances of *Answer-making*, as Darren makes repeated attempts to steer students toward one particular response without attending to student reasoning. In Lines 36-37, he goes as far to tell S4 to just say "minus 30 plus 25." We would argue that there are multiple acceptable responses to this question, and instead of centering a discussion around the merits of each choice, Darren focuses on making each student adhere to the same convention.

In terms of assessment, Darren focuses on student's written responses and uses questioning only briefly to probe understanding by asking a series of I-R-E style questions (Lines 11-16).

Caleb

In this episode Caleb discusses a series of experiments in which two gliders of unequal masses collide, with the rebounding glider leaving with a different momentum between each experiment:

Caleb: How's this going for you guys?

S2: Good!

S3: Fantastic.

[Cross-talk]

S3: Swimmingly. I've never heard that one before.

C: Looks like you guys are crushing it.

S3: Always crush it. Every day.

C: Let me ask you guys something. So what if I told you that on this problem, B3 actually had the longest velocity vector, B2 had the middle, and B1 had the shortest. Would your answers change?

S3: Yes they would.

C: How?

[pause]

S4: B3 would have the greatest momentum?

S3: Well, A3 would have a very, very large backward momentum. This one would have a much smaller backward momentum—or if not, no backward momentum. And this one would just probably stop, depending on how big that arrow is.

C: [nods slowly] OK. So how would you rank the momenta of blocks B1, B2, and

B3?

S4: In this case?

C: Yeah, in this special case that I've drawn in red.

S4: B3, B2, B1. 'Cause we know that they're increasing in velocity, I mean mass, and they're increasing in velocity.

C: This is a pretty trivial question, right? OK, cool.

S3: We're crushing [unclear].

[laughter]

C: OK. I only ask you guys that because I wanted to point out that this is information that you didn't use.

S2: That it's a what?

C: Right, these velocity vectors? Like, what if I just had not told you what they were? What if you were given no information on them? Could you solve the problem?

S3: Yeah. 'Cause you know the final momentum. It's conservation of momentum.

C: [nods] That's all. That's all. Don't let me slow your roll, brah.

Although he doesn't prompt for consensus in this episode (as he does in others this week), we observe Caleb asking multiple questions that extend the tutorial content (Lines 8-10, 31-32), a *Constructive* approach to assessment. This is a relatively brief interaction for Caleb, and it may be inferred based on other episodes that this group does not need as much guidance as others. Caleb's statements seem to support this, i.e. "You guys are crushing it".

Oliver

S3: [Reading] "On the basis of your results, describe how you can tell whether the momentum of an object or system is constant by inspecting the free-body diagram for the object or system."

Oliver: So what did you guys think about the free-body diagrams?

S2: Half the time they seemed a little out of place.

O: (laughs) OK, OK. So which way does block C accelerate?

S3: C accelerates that way. *[gestures left]*

O: OK. So net forces should be...

S3: That way. *[gestures the same way]*

O: To the left. [Nods] And uh, which way would D accelerate?

S3: It doesn't.

O: It doesn't, OK. So net forces...

S2, S3: Zero.

O:—cancel. So where does the horizontal forces come from on block D?

S3: One is, one going this way is from block C...

O: Block C, yeah. [Nods]

S3:...and then the other one is the normal from being fixed in place.

O: [Nods] OK. Good. And the net force on the entire system?

S3: Is that way. *[Points left]*

O: To the left. Yeah. [Nods]

Based on this episode, Oliver's questioning strategies haven't changed much from Week 4, as he still relies on repeated closed-form questioning with an immediate evaluative response, and very infrequent prompts for student reasoning.

Terrence

This episode illustrates Terrence's "Would you bet money on it" approach regarding challenging students' certainty, in this case regarding conservation of momentum:

Terrence: Whoa, whoa, whoa. I'm pretty sure this arrow is bigger than this arrow.

S2: It is.

T: Can you explain that to me?

S2: (laughs) Well, since the momentum of this one is equal to the whole system because this one isn't moving, and because the glider A bounces back, then to conserve momentum this one has to have—

T: Whoa, whoa, how do you know momentum's conserved?

S2: Um, 'cause it's a fact?

T: It's a fact?

S1: It's always conserved.

T: Would you take that to Vegas?

S1: Yeah.

T: You would lose money in Vegas.

S1: What? Momentum's conserved... when there's no friction. An isolated system.

T: An isolated system.

S1: Yeah.

T: Which means what?

S1: [Unclear, laughter] That means there's no external forces.

T: How do you know there's no external forces?

S1: [Unclear]

T: So that's how you know momentum's conserved.

S2: So an isolated system with no external forces?

T: Yeah, that's what an isolated system is.

S2: Gotcha.

S1: So if there was like, friction, it wouldn't be conserved? It would just lose some of its energy to friction and then...

T: It would depend. Would you still include the Earth?

S1: Yeah.

T: Then it would be conserved. If the system doesn't include the Earth, then it's not conserved.

S1: Why's that?

T: So if you have friction and you're including the Earth, you're saying that force is an internal force. But if you exclude the Earth, like we usually do, then friction is an external force.

S1: Oh, OK.

T: It depends on how you define your system.

Here Terrence takes a primarily Conceptual approach to understanding momentum conservation. The students' initial idea that momentum is always conserved occurred multiple times during this week, and Terrence tended to challenge this assertion (much as he does in the above episode). We also observe Terrence prompt for student reasoning three times (Lines 4, 8, & 20).

Joanna

In this episode, Joanna is called over to a group by a student having trouble:

S3: *[Raises hand]*

Joanna: *[Pulls up a stool]* OK.

S3: So I am having trouble with part 3, like, fixed block. It says system S but it never says what's included in system S. And I feel like...

J: Just blocks C and D.

S3: Just blocks C and D, and not the Earth? Or whatever it's fixed to?

J: Right.

S3: OK. So then D doesn't have a change in momentum, so the total momentum of the system does change?

J: [Nods]

S3: Alright.

J: Does A experience—or, it's a block. Does C experience a change in momentum?

S3: Yes.

J: Does D?

S3: No.

J: No. So when you're looking at the momentum of the system, how do you calculate the net momentum?

S3: Just momentum of one plus momentum of the other?

J: Yeah, you add up all the individual parts. In this case one of the parts stayed the same, one changed, then the entire thing must have changed.

S3: But if it did include the Earth, 'cause it doesn't say it can't...

J: If it did include the Earth, then yes I agree with you. It's really good that you thought of that too, because a lot of students don't take into account the fact that that means it must be (importing?) the momentum of something else. Momentum is conserved, that's like, not a question. It just depends on where you draw the bounds of your system.

Joanna's questioning is primarily I-R-E form in this episode, which also happens to be completely one-on-one with S3. Although she starts giving extended explanations toward the end before leaving, Joanna also praises S3's contribution (Lines 22-23).

5.2.2.3 Week 14

Week 14 covered the "Buoyancy" tutorial.

Darren

Darren's practices during the final week were ultimately very similar to those he used earlier in the semester:

Darren: So how you guys doing. On page 2?

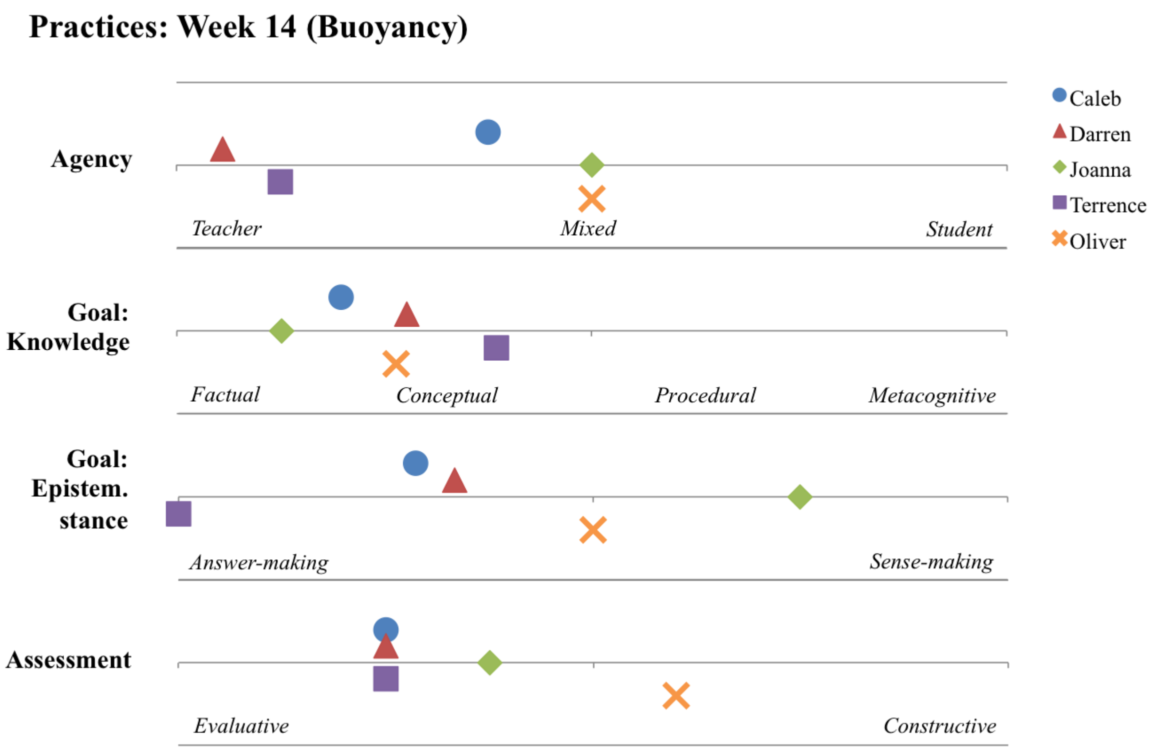

Figure 5.12: Collapsed representation of how TAs compared in their coded practices during Week 14.

D: So this question right here, number 3, is very, very, very important key point in buoyancy. So the question's asking how does the sum of all the forces of the block by water differ from the previous case? Like so this one sinks and the other one floats, and like, you guys what, said it's the same?

S2: Yeah.

D: That's very, very crucial. What does that say about buoyancy force? Does it depend at all on mass?

S2: No.

D: That's very important. So like, all that matters is like the volume of the, y'know, it takes up. And also like the density of the object. But the bottom line is if you have 2 objects, like in this case, just 'cause it has more mass doesn't necessarily mean it's gonna have a different force, in fact in this case it didn't. That's like the key thing, like, in this tutorial that I would try to take away is like, how does volume affect buoyancy force, and how does mass affect buoyancy force. So if you make that distinction, you'll be set for the final for like stuff on buoyancy. So does that make sense?

S2: Yeah.

D: Do you guys have any questions at all on this page at all?

S2: Um, for C3, the vector sum of the forces on the block by the surrounding water, I'm not sure, would that be greater than? For, compared to. . .

D: (reading from S1's book) Oh, um, "the vector sum of the forces on the block by the. . . "

S1: When it goes down deeper.

D: Oh, it's deeper. OK, so, OK, so what's that gonna mean, you're gonna have, obviously a much greater, uh. . .

S1: Buoyancy.

D: Well, remember, the buoyancy, does it matter like where it's at, like for buoyancy?

S2: No.

D: See, it doesn't matter. So see if that can—I mean, I can come back in like a minute. See if you can think about that, like it doesn't matter where the depth is. Like, yes, the pressure downward's gonna be much, much greater now. 'Cause we're a lot deeper. So. . .

S2: 'Cause you have the force of the water pushing it down too, or. . . ?

D: Uh, yes, but so if the buoyancy force stays the same, what does that mean? If you have greater force pushing down, but yet the sum of all the forces by the water is the same, what does that mean about the force pushing up from the water below it?

S1: Um, it's less?

D: Well, I mean like, uh, I dunno, you might not even be able to answer that. Um, well, OK. Remember, the sum of the forces by the water has to equal— it doesn't matter how deep it is, like this vector will stay the same, right. So, see if you can—

S1: So then it's the same.

D: I think it might be the same. *[Flips open book]*

S1: If it's still the vector sum of the forces by the water…

D: Yeah, it's the same. And that's why, like remember, this doesn't change. I mean, it doesn't matter how deep something is, remember the equation for buoyancy force is $\rho V g$, right? I mean, have you guys gone into that at all in class?

S2: Yeah.

D: I mean, you don't have to memorize formulas, that's why the formula sheet is there. But if you look up in your book, it's the density of the fluid times the volume of the water, fluid, displaced times gravity. I mean, that has nothing to do with depth. So the vector sum of all the forces still has to be the same. Is that OK?

S2: Yeah. Thank you.

D: Alrighty.

In this episode we once again observe Darren emphasizing a "key point" of the tutorial, in this case the buoyant force being independent of object density or depth. His questioning also tends to rely on students self-assessment of their understanding ("...does that make sense?", "Is that OK?"). We find it interesting how Darren downplays the reliance on rote memorization of formulas after he just prompted them to remember the equation for the buoyant force (Line 50).

Joanna

S2: This is density of the liquid, right? For $\rho V g$?

Joanna: What does the V represent?

S2: Volume of displaced liquid.

J: Yeah.

S2: So the buoyant force depends on just the volume of the object?

J: [Nods] Mm-hmm.

S2: OK.

J: One of the things that confuse students is the fact that it sinks sometimes and floats other times, and they think it somehow has to do with the densities and things like that. And it really doesn't. It has to do—the density yes, but not directly the way you got it here. The buoyant force stays the same, regardless of the density of the object. It's just that having a higher density with same volume—therefore the same buoyant force—makes it have a greater weight. So it has a greater downward, same upward force. It's not that the upward force decreases. That's where a lot of students get off on the buoyant force.

S4: Unless the volume changes, and then the buoyant force would change.

J: Right. So for C, why did you guys pick the answers you did?

S4: So, I was picking that because for the first part, the volume below the block is less, so that force is going to be less, but on top of the block is greater, so that must mean greater down and the difference is going to be the same.

J: So you're telling me that *[holds hands flat, one above the other]* the upward force on the bottom of the block gets less *[moves lower hand down]*, and the downward force on the surface gets greater *[moves higher hand up]*.

S4: So the difference between the two is still the same.

J: So they were like this, and now they're like this *[spreads hands apart]*.

S4: Oh.

J: So you're telling me that's going to stay the same?

S4: [Unclear]

J: So do you guys remember the expression for pressure at a certain depth?

S3: The force, the perpendicular force over area.

J: Great. You know a way to write it in terms of liquids, things like that, like the pressure, like 8 feet below water?

J: So your pressure at any given height is going to be$\rho g h$ *[writes on sheet of paper]*, plus usually atmospheric pressure. So this is the density of whatever surface it is you're under, g is gravity, h is the distance between the surface.

S4: Sorry—the ρ is the density of the object, or—?

J: Of the liquid that you're being submerged. The thing that's like, around you. So in this case as the block is lowered, what will happen to the pressure that is on the bottom of the block?

S3: It'll go up.

J: It'll go up. And since pressure is related directly to force, pressure equals force over area, what does that mean about the force?

S2: Both increase.

J: [Nods] They both get greater. So, before they were at this level *[holds hands up]*, now they both increase this much *[lifts hands in parallel]*. That make sense? 'Cause you had all of this other stuff right, it was just right there, so. Do you have any other questions or anything?

Joanna makes several moves to attend to student thinking in this episode. In Line 17, she prompts for the students' reasoning, and in Lines 21-23, she restates S4's position using gestures to help him clarify his argument. Joanna also emphasizes multiple content goals in her questioning and explanations, including Factual and Conceptual.

Terrence

Terrence's instructional approach changed quite a bit during Week 14, as illustrated by the following excerpt:

Terrence: Hey, guys.

[Mumbled "hello"s]

T: How we doing?

S?: Good.

T: Is everybody happy? *[sits down]*

T: Are you happy?

T: So how are we, guys?

[looks at S1's tutorial book]

T: *(reading)* Greater, greater, same. Cool. That's a good response. So have you guys figured out what the buoyant force is? No? You still don't know what that is?

S3: Uh, what? What problem?

T: Buoyant force. Well, yeah, do you know where it comes from?

S1: The mass—of the—

T: So if I have a fishbowl... and I look at the forces on a block of water, right? Is a block of water going to move up or down? In a fishbowl? No. So the forces are going to be exactly the same. Force up, force down, and some weight, right? (pause) So if I draw—write that out, I get F up minus F down, minus W is equal to zero. Newton's Laws. Right? So I know that F up minus F down is equal to W. And I know that my forces in a fishbowl are ρ times the volume—or times A times h—times g, right? You know what I'm talking about. So if I were to plug this in here using different h's, so if I had like an h_1 and h_2, where h_2 is the bottom, just call this distance h_2 and this is h_1, right? What am I going to get? Well, this is going to become $\rho A \Delta h g = W$. That's what we call the buoyant force. So basically the amount of water you displace tells you how much force you're gonna have pushing back up. 'Cause this is the volume of an object now, right? Δh, Δh corresponding to this. So what you're seeing is that your buoyant force comes from the amount of volume of the water you displace. And it has a force that's equal to the weight of the volume of the water you displace. 'Cause this is the density of water. And so when you're applying that to, y'know, now if I have a block of brass in the fishbowl, right, this is brass. Right? Well, now the free body diagram, I can draw that with an F_B and some W, and obviously if F_B minus W is greater than zero, it's gonna go up, and less than zero it's gonna go down. So that explains why heavy stuff sinks in the water and stuff that's not as dense as water rises. So is that elucidating a little bit, maybe?

S1: *[nods]*

T: It's OK? Helpful, kinda?

S2: Yeah.

T: Any questions? *(pause)* So I'll let you guys keep working... or should I quiz you?

S3: Let's do the work thing.

T: Do the work thing. You don't like my quizzes.

LA (off-screen): Quizzes? I thought we didn't give quizzes.

T: Well I give quizzes. Verbal quizzes. Which makes it worse.

We have no evidence of Terrence giving extended explanations anywhere near this length in prior weeks, yet he was observed to deliver this same lecture to multiple groups during Week 14. During his explanation, Terrence attends to formulas, definitions and Procedural knowledge involving the use of free-body diagrams. He talks continuously for nearly three minutes without prompting for any kind of student contribution.

Comparison with other weeks indicates that this lecture approach does not appear to be part of a semester-long shift in Terrence's practices, but rather a specific change he makes to compensate for a particular aspect of this tutorial. In fact, Terrence confirmed this when commenting on this episode during his end-of-semester interview, as we will discuss in the next chapter.

Additionally, this episode provides some additional insight into Terrence's preferred forms of assessment. In Line 9 he focuses on written student answers, and at the end we see a mention of the "verbal quizzes" he described during his interviews, which are essentially challenge questions to test the understanding of students who have finished.

Caleb

Caleb also used the "block of water" thought experiment during the "Buoyancy" tutorial, after hearing it from Terrence during the weekly prep meeting. However, he incorporated it in a slightly different manner:

Caleb: OK, OK. So someone, when we were doing this tutorial on Monday, one of the other TAs I thought explained it in a pretty good way. *[Starts to draw]* They said, so consider you have a tank of water, and then you just want to look at a little cube of water in that tank. Right? So, it's kind of weird to think about a little piece of water inside a body of water, but we could do that, right? We could draw a free body diagram or something like that for this. So what are the forces acting on that little bit of water? [S3], give me a force, man. Bail me out here.

S3: Gravity?

C: Gravity, yes. Awesome. So there is some, um, weight, some force of gravity exerted by the Earth. Right? And then, there's water all around it, right?

S1: *[Adds to drawing]* Going up.

S4: And on the sides.

C: There's water on the sides, pushing. There's water below pushing up. Water above, pushing down. What do you guys think about the net force on this block of water?

S1: Zero?

C: [Nods] Why?

S3: It's not moving.

C: Yeah, 'cause this little block of water isn't zooming around inside the tank. I mean, if you think of like, maybe just a bucket of water that you would sit on a table, y'know, the water is pretty still. If you put like a drop of dye in it you can see it spread out slowly. That is like, small-scale diffusion. On a macroscopic level, F_{net} is zero for that little block. OK, so what's that tell us? That tells us that the sum of these forces has to be the opposite of gravity, right? If you guys will agree with me that there are no other forces.

[Various nods]

C: So... that is like shorthand for what we call the buoyancy force. It's the sum of all these pressures of like the water around it, yeah. Or whatever fluid it is. OK, so we abbreviate these with like, F_B up. So when something floats, that means that the force of gravity is less than that buoyancy force, right? When something doesn't float, it's because this force of gravity is greater than that buoyancy force so it accelerates downward. If something is just sitting in water and not moving, like our little block of water, that means that these two are equal. Right?

S1: Mmmm. Makes sense.

C: So the mass of—so say this is not water, so this is now some solid, right. If I make it heavy enough, will it sink?

S3: Yeah.

C: Yeah, it will. Here's a question. If I make it—when I make it heavier, is this force changing, or this force changing, or are they both changing?

(pause)

S1: Just that one?

C: Yeah.

Here we observe more explanation on Caleb's part than in some of his other episodes, but compared to Terrence's episode he provides more opportunities for students to contribute to the derivation. Caleb also prompts for student reasoning (Line 18) and asks extending conceptual questions (Line 40). Additionally, the overall focus of the conversation is not on the expression for buoyant force (as it was for Terrence), but rather conceptual aspects such as the dependency on object density.

Oliver

This is another characteristically brief episode for Oliver, beginning with him checking in on a group of students:

Oliver: Any questions over here?

S3: I don't think so.

O: So how did you rank the forces on the different surfaces?

S3: Well, the buoyancy was greater. Wait, of 3? This one?

O: Yeah, like, you're supposed to rank the vertical forces.

S3: We said the buoyant force is greatest because if it's float[ing], it's gonna rise.

O: So which is the buoyancy force? Is that the one pushing up or down?

S3: Pushing up.

O: Up. OK, so actually, so when we say buoyancy force, we actually usually mean like the sum of all the forces from the water. So it's like the difference between the downward and upward. But uh, yeah. So how did you know

12 that the upward pointing one is bigger?

13 S3: Because it said that it floated.

14 **O:** Oh, OK, so it's going up.

15 S3: So it'd have to rise.

16 **O:** OK.

Oliver's average interaction time was consistently among the shortest of all the Physics 1110 TAs, including during Week 14. In this episode. Oliver's choice of question in Line 7 is interesting as he constructs it to be a bit of a trick question, since neither of the choices he offers is correct.

5.3 Discussion & Conclusions

We conclude by returning to the research questions presented at the beginning of the chapter: *(1) Can we distinguish stated beliefs and practices for the expanded set of TAs?*

Figure 5.13: Post-interview coded belief results for all 8 TAs described in Ch. 4 and Ch. 5.

As in the previous study, we observed variation between TAs in both beliefs and practices that could be distinguished using the TA-PIVOT framework. Fig. 5.13 shows how all 8 TAs compared in their post-semester coded beliefs along the TA-PIVOT dimensions. Again, some TAs tended to be more aligned with particular aspects of the tutorial approach in their stated beliefs than other TAs.

Figure 5.14: Practices coding results for the Fall 2011 TAs, aggregated over all weeks.

In Fig. 5.14 we present aggregated coding results for the Fall 2011 TAs. We notice first that the TAs' "centers of gravity" appear to be toward the left side of the chart, which is less aligned with the curricular approach. Looking across the dimensions, the TAs' practices appear to be "stratified" relative to one another. That is, the TAs' relative positions along each dimension appear to be coupled (for instance, compare Darren's points with Caleb's).

(2) Can we observe differences in individual TAs' beliefs and practices across weeks? If so, is there evidence of consistent development of particular beliefs and/or practices?

As illustrated in Fig. 5.7, we were able to distinguish shifts in stated beliefs for the Fall 2011 TAs as measured by the TA-PIVOT framework, although the size of the shifts were small compared to their overall span of coded statements. Hence it appears that TAs tended to persist in particular beliefs, despite teaching in a research-based classroom environment that is structured to promote student-centered instruction. In other words, it does not appear sufficient to simply place TAs in instructional environments that are aligned with student-centered pedagogy in order to impact their beliefs about teaching.

This result is consistent with prior research on the development of teacher beliefs, which suggests that pre-service teachers' beliefs change over a timespan of several years. Furthermore, four of the five TAs in the Fall 2011 study population entered with some form of teaching experience, some in environments very similar to the CU tutorial model. It is possible that these prior experiences served to engage these TAs in refining beliefs about teaching before their arrival at CU, which may have reduced the "novel" impact of teaching in a transformed environment.

Although TAs' practices did not appear to undergo consistent overall shifts over the course of the semester, we do observe differences, suggesting that certain TAs tended to utilize different strategies for different tutorials. (For instance, Terrence's use of direct lecturing during Week 14.) We hypothesize that the structure and/or content of the tutorials may be a factor in these differences in approach.

(3) Do we observe instances of coordination and/or discoordination between between beliefs and practices?

As in section 5.2.1.3, we can use a 2D representation to illustrate coordination between TA beliefs and practices, as shown in Fig. 5.16. Here we have plotted aggregate coded practices against post-semester coded beliefs. In this representation, the location of a TA indicates the degree of coordination between his or her beliefs and practices. Points along the X-Y axis indicate coordination between stated beliefs and enacted practices, with points further from the origin being more aligned with the curriculum. Points that are above or below the diagonal indicate that a TA's

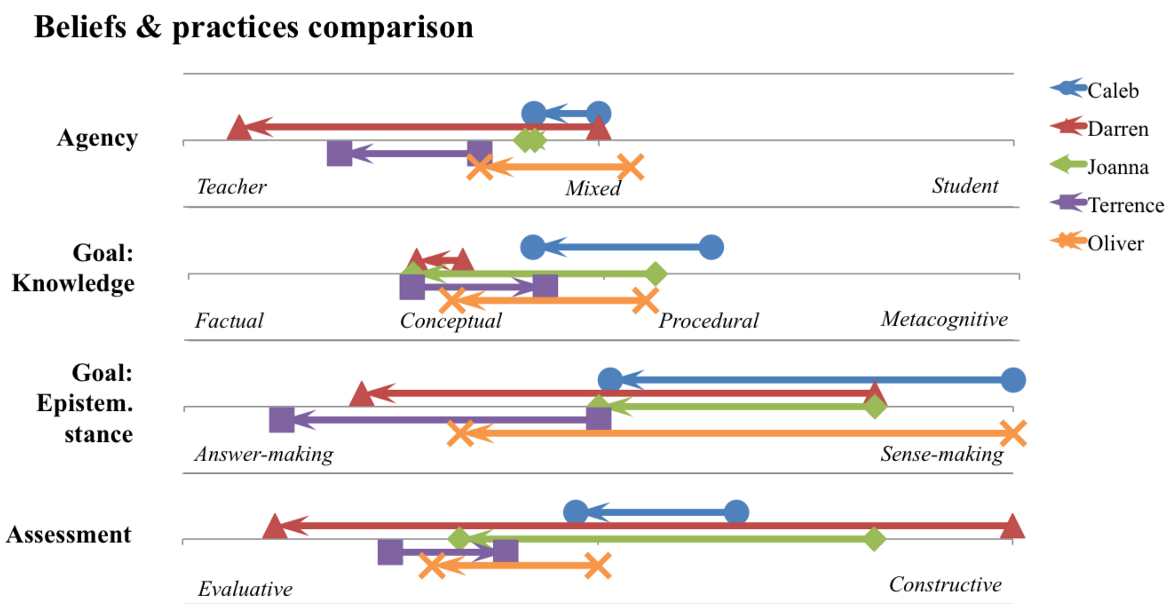

Figure 5.15: Comparison of post-semester stated beliefs with aggregated practice codes. Arrows start at beliefs and end at practices.

stated beliefs are more aligned with the curriculum than practices, or vice versa.

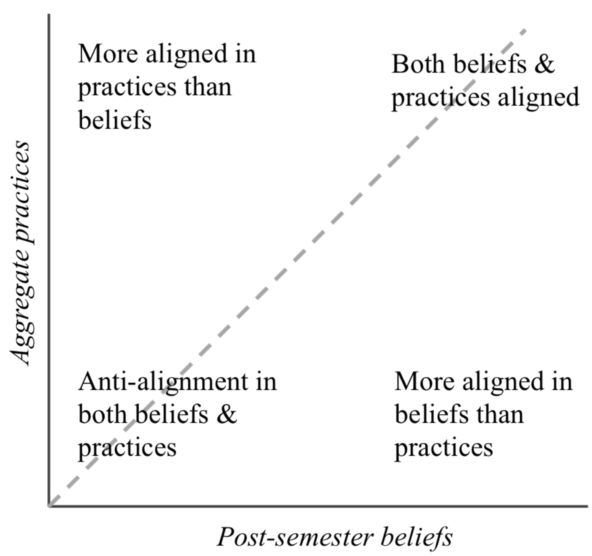

Figure 5.16: How to interpret 2D plot of practices versus beliefs.

In Chapter 4 we observed instances of TAs whose stated beliefs were aligned with curricular

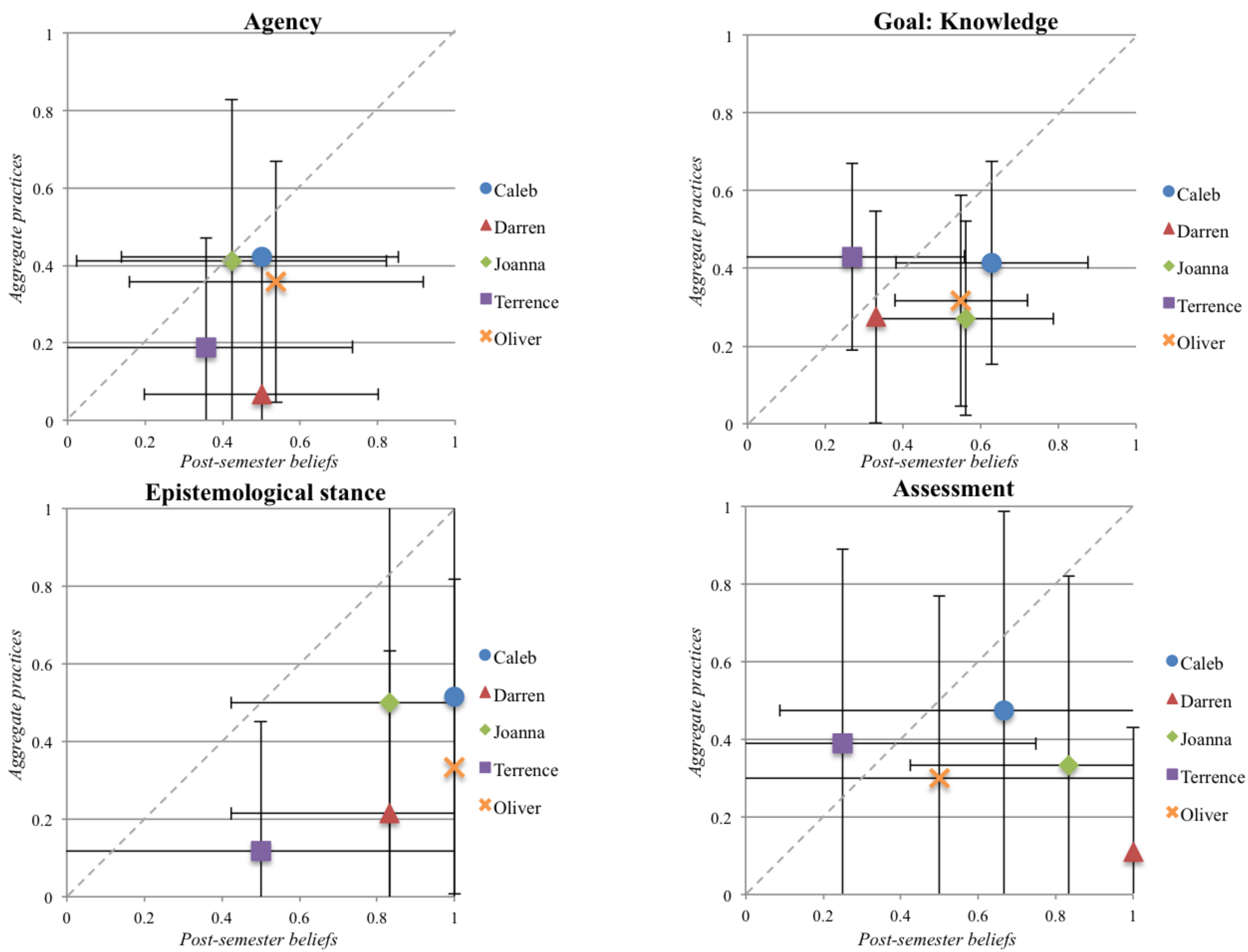

Figure 5.17: 2D plot of TA practices versus beliefs.

goals (but not aligned with their practices), and TAs whose stated beliefs aligned with their practices (but not the curricular goals). In Fig. 5.15 we have aggregated TAs' coded practices across the semester and plotted them alongside the post-semester beliefs. (The arrows are directed from beliefs to practices.) We observe similar instances for the TAs studied during Fall 2011. Overall there is a general trend away from alignment with the curricular approach (i. e. toward Teacher-centered agency, Answer-making, and Evaluative assessment).

We note that Darren tended to have the largest differences between coded beliefs and practices. On the other hand, Terrence demonstrated a relatively small difference between coded beliefs and practices, although each of these tended to be anti-aligned with the tutorial approach. We may therefore wonder whether TAs such as Darren are aware of the difference between their described and enacted practices, and whether they would recognize a disconnect upon viewing themselves in the classroom. We will address this question in the next chapter.

As we described previously, perceived barriers to implementation are one explanation for why instructors' observed practices may not align with their stated beliefs. Talking to these instructors and presenting them with examples of their own practices affords a rich opportunity to approach the question of why they chose to engage in certain practices but not others. At the end of the post-semester interview during Fall 2011, these five TAs commented on segments of video drawn from the video data inventory. In this case the TA video reflections provided information regarding the underpinning motives for these differences in approach. A number of preparation models include video consultations such as these to scaffold practitioners' ability to reflect upon instructional practices. In the next chapter, we will describe in detail how this model could be incorporated into a broader program for professional development.

References (Chapter 5)

[1] R J Beichner, J M Saul, R J Allain, and D L Deardorff. Introduction to SCALE-UP: Student-centered activities for large enrollment university physics. 2000.

[2] David R Krathwohl. A revision of Bloom's taxonomy: An overview. *Theory into practice*, 41(4):212–218, 2002.

Chapter 6

Conclusions & Future directions

6.1 Conclusions

In the preceding chapters, we documented an analytic framework for characterizing physics Teaching Assistants' beliefs and practices, and used this framework to examine the range of stated beliefs and enacted practices for introductory physics TAs. In doing so, we uncovered instances of apparent tension between how these TAs described and carried out their roles as instructors. Furthermore, by tracking TAs over the course of a semester, we were able to document shifts in TA beliefs (the size of which varied between TAs), as well as further notable instances of dis-coordination between beliefs and practices. In light of the conclusions of Chapter 3, these findings encourage us to consider how we may extend a successful model for focusing attention on student difficulties and direct it toward the alignment of TAs' beliefs and practices with curricular goals.

Prior research has examined similar instances of consistency and inconsistency between described and observed practice, with reflection on the part of the instructor appearing to play a critical role [1]. In this chapter, we examine the role of structured self-reflection in TA professional development, as well as the utility of the TA-PIVOT framework in facilitating this process. We begin by describing the video reflection activity that the Fall 2011 TAs took part in, which provides some insight into a few of the instances of dis-coordination we called out in the previous chapter.

6.2 Video stimulated recall

Our post-semester TA interviews included a brief (30 minute) segment in which the TAs viewed and commented on 1-2 episodes of their own teaching. These segments were not planned at the beginning of the semester, and were arranged in response to one of the TA subjects (Caleb) expressing interest in reviewing his own teaching for his own professional benefit. We asked Caleb if our discussion could be included as part of the research analysis. When he agreed, we contacted the other TAs to ask if they would be willing to view and comment on their own video as an optional activity. All 5 TAs who were videotaped during the Fall 2011 semester agreed to comment on their own teaching as part of the final interview. We included the video commentary segments at the end of the final interview so as not to influence responses to questions earlier in the interview protocol.

First, as researchers we were curious whether TAs would attend to the same general categories of features that made up the TA-PIVOT framework. Second, we viewed this as an opportunity to explore self-reflection as a component of TA preparation. We are careful to specify that these conversations provide *insight* but not *validity* into TAs' thinking. That is, we cannot accept TAs' descriptions of their practices after-the-fact as a "true" understanding of what actually happened in-the-moment. Nonetheless, TAs' comments on their own practice provide valuable insight regarding the context of the episode that may not be apparent to us as researchers.

We purposefully avoided selecting episodes to examine specific practices or classroom incidents. Instead, episodes were selected based on being a reasonable length (roughly 2-3 minutes) so that the video could be played back multiple times if necessary, and we selected more recent episodes to increase the likelihood that the TAs would be able to remember the general context. Prior to viewing the episodes, the interviewer communicated to the TAs that he did not have a "motive" for selecting the particular episodes that were viewed, in order to *(1)* reinforce the non-evaluative nature of the session, and *(2)* avoid having the TAs focus on identifying a particular "flaw" that would have led to a particular episode being chosen.

Here we discuss common themes that emerged from the video stimulated recall.

Promoting student agency

In watching their own practices, some TAs recognized missed opportunities to promote student agency in the learning process. For instance, while viewing an episode in which he drew a diagram for a table of students, Darren commented:

> I could maybe even ask someone here to draw, rather than me doing it, maybe ask someone to—"How about you draw the after vector?"... I could probably have them try to draw it out, instead of me doing it. 'Cause like, I feel like just in these settings, sometimes it could easy for like one person to kind of zone out, you know what I mean? So like, having people be involved in it will like, you know, keep them involved. [Darren post, 00:49:55]

We have seen that Darren considers it important to identify the main "big ideas" of the tutorial, but in practice he tends to communicate these ideas in a direct manner instead of asking the students to generate them on their own. This may be another opportunity for Darren to identify a specific teaching strategy that he could incorporate in a more student-centered manner.

Terrence watched an episode from the "Buoyancy" tutorial, in which he spent several minutes explaining Archimedes' Principle and deriving the formula for the buoyant force. (This was the same episode we discussed earlier, in which Terrence used the canonical approach of identifying the forces acting on a stationary "block" of water in a tank.)

> This is somewhat of a passive listening learning that I make them do, but again, they told me they didn't know what the buoyant force was. So, y'know, I recognize that this is somewhat against making them be active learners because I'm showing them how this works. But um, on that tutorial when I read through it, I felt like if you didn't know the [buoyant] force equation, it was never going to make sense to you. And so I made sure that I went and... did that. [Terrence post, 00:46:26]

Here Terrence recognized that his instructional approach was teacher-centered, but felt that students needed to know the buoyant force equation in order to do the tutorial. He also indicated that this was an explanation he gave to every table if they didn't already know Archimedes' Principle. Recall that Terrence stated in his interviews that he believes students don't learn from being lectured to. He also specified that this type of extended explanation was not part of his regular practice earlier in the semester, but made an exception for this tutorial.

Terrence's opinion is interesting as the tutorial places considerable emphasis on what *causes* the buoyant force, by comparing the magnitude of forces a fluid exerts on each side of a submerged object. However, tutorial does not derive the exact formula for the buoyant force, which appears to be what Terrence means by "what the buoyant force [is]."

Joanna also attended to the fact that she did not involve more students in the discussion:

> Um, I didn't include all of the students in it. [This student], usually— she's like a very smart girl, she sometimes would like falter in that course if she wasn't really paying attention, but she would sort of usually get bored when I was explaining stuff, she was a very like, "Just give me the answer to this, and then I'm done with stuff." And she would—like how she started (smacks lips) whatever-ing towards the end there. Um, I dunno. I usually, even though I'm like discussing, would try to look around the table and make sure I am engaging all the students even if I'm not directly talking to them or asking questions. [Joanna post, 00:46:38]

Joanna recognized that not all of the students were involved in the discussion, but did not offer an alternative strategy beyond her usual approach of making eye contact with all the students.

Questioning & assessment

Darren also commented on how he tended to assess student understanding, and again described a practice would have used in hindsight:

> So if I would have to do this again, I would say like, "Could someone explain to me why angular momentum is conserved?" rather [than] "Does everyone agree?" So I feel like people would be like—I mean, they may very well understand it, but I feel like there's some people who are just going to be inclined to say, "Oh yeah, like, I understand it," when they may not. [Darren post, 00:47:32]

Here Darren identified a questioning strategy that he used often in the classroom (and that we coded as low-level assessment), and described how to make it more reflective of student understanding. Although we did not have Darren "code" himself, this is an encouraging preliminary indication that the features we identified in developing the TA-PIVOT framework are also salient to our research subjects.

6.3 Revisiting TA preparation

Recently, Gray [2] was able to document changing conceptions of teaching for first-time undergraduate Learning Assistants (LAs) serving in the same environments as the TAs in our studies. Of course, these LAs are engaged in a semester-long pedagogy course that includes frequent opportunities to consult literature, reflect upon practice, and discuss with peer instructors [3]. We must also consider the recommendation from Goertzen *et al.* that TA professional development should address and seek to refine beliefs rather than specific practices [4]. To illustrate this, we borrow Schön's model of "double-loop learning" [5], diagrammed in Fig. 6.1.

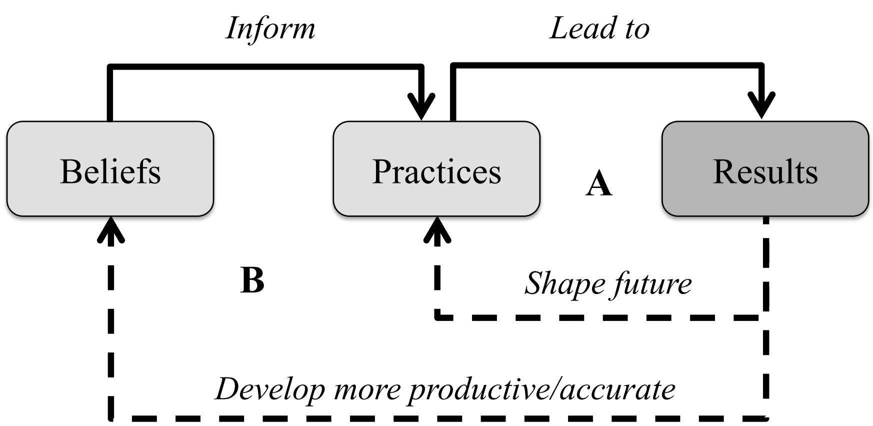

Figure 6.1: Single- and double-loop learning. In single-loop learning (A), practices are adjusted in response to outcomes. In double-loop learning (B), these outcomes lead to the refinement of beliefs that will in turn inform practices. Adapted from [5].

As described in Chapter 3, it is desirable for any enhanced efforts to operate within existing institutional structures and constraints, including time and resources. For instance, while we might expect an LA-style pedagogy seminar to influence TA beliefs and practices, it would represent a significant addition to TAs' weekly time commitment that would come at the expense of their ability to engage in other course aspects. Nonetheless, we may consider the particular features of this and other existing models to consider how to support the development of TA beliefs that are aligned with the curriculum.

The key features of the weekly preparation modifications we introduced in Chapter 3 were:

(1) A focus on observation & discussion

(2) Explicit opportunity for reflection following practice

(3) Structure around a particular component of teacher knowledge (in this case, student difficulties)

In the next sections we address how these features could be extended to TA professional development, along with existing models that could be drawn upon in doing so.

6.3.1 Observation & discussion

Teachers' ability to notice features of classroom situations is recognized as a key form of professional knowledge [6, 7]. These researchers use "learning to notice" to mean identifying significant or meaningful features of classroom situations; connecting specific classroom interactions to more general instructional principles; and using contextual knowledge to reason about classroom interactions.

We have seen in the previous section how even a brief stimulated recall session can lead TAs to rethink particular strategies, assess their effectiveness, and consider alternatives. Extensive work on video as a form of stimulated recall has been conducted by David Taylor-Way [8]. Taylor-Way identifies three critical factors for consultants to make effective use of video recall: *(1)* helping clients organize their own concepts of teaching toward constructing a framework of professional knowledge about teaching; *(2)* creating a safe and comfortable atmosphere for clients to reflect upon their own beliefs; and *(3)* encouraging clients to take ownership of the session by allowing them to control the direction of conversation and summarize points for themselves.

The critical incident technique (CIT) is commonly used in service fields such as nursing to help practitioners deconstruct specific on-the-job events in order to better understand their roles in professional settings. A "critical incident" is one that causes a practitioner to stop and reflect on its meaning. Rather than solicit answers to specific questions, a critical incident interviewer instead asks a worker to describe a critical incident, its causes and outcomes, as well as the specific actions taken and any impact on their future behavior. This technique has been applied to educational settings [9].

These methods are structured to be completed in the company of an expert consultant, but other video-based activities have been incorporated into community-based models for professional development. For example, "video clubs" involve teachers meeting regularly to view and discuss videos of one another in the classroom [10]. This type of model could be incorporated into workshop-based professional development opportunities for TAs.

6.3.2 Opportunities for reflection

Self-reflection on practice is widely acknowledged as a powerful tool in teacher training, and indeed, professional development more broadly. Schön describes *reflection-in-action* as in-the-moment rethinking of strategies in response to unexpected situational developments [5]. In contrast, *reflection-on-action* takes place after practice and relates to the situational approach that was taken. For example, the TAs video commentary activity described in the previous chapter is an example of reflection-on-action. The goal of developing professional vision would be to scaffold toward reflection-in-action so that TAs are better able to consider instructional strategies during practice.

The CU Learning Assistant program seminar includes weekly written reflections on teaching practice, as well as longer article reports and a final project. Although all of these reflective opportunities would not be feasible for graduate TAs to complete, the use of brief weekly reflections could serve as a productive first step toward scaffolding TAs' reflection-in-action. Furthermore, a shift in framing of the weekly preparation meetings could support this model by devoting part of the time to sharing TA/LA reflections or deconstructing specific classroom events.

6.3.3 Structure

The PCK intervention in Chapter 3 was structured specifically around student difficulties and misconception, which provided a common focus for the participants. Here we describe alternative “anchors” for discussing beliefs and practices.

TA-PIVOT dimensions

In the preceding chapters we have built up the TA-PIVOT framework as a categorization scheme for beliefs and practices. We argue that the TA-PIVOT dimensions could serve to structure and focus TA attention on particular components of instructional beliefs. In Table 6.1 we provide some example targeted questions that could be used to guide TA self-reflection or discussion. Some, but not all, are drawn from questions in the interview protocol. The benefit of this approach would be for practitioners to focus on a single specific segment of their teaching, which could be alternated between professional development sessions.

Agency	• How do you usually encourage students to work together? • When do you think it’s OK to directly explain a concept to students?
Goals	• What do you want students to learn in this course? How is that reflected in your teaching? • How do you encourage students to make sense of physics concepts?
Assessment	• How can you usually tell when students have learned? • What types of questions to you tend to use most frequently?

Table 6.1: Possible themes for TA reflection and/or discussion, drawn from the TA-PIVOT dimensions.

Common challenges

Many TA training models do not actively provide opportunities for TAs to discuss the types of challenges they face in the classroom and hear effective strategies used by their peers. For instance, a commonly cited constraint in small-group classroom environments is how much time the instructor is able to spend at each table. In our interviews, several TAs explicitly mention that they consider it important to visit each group at least once during the class period. This time constraint places a demand on TAs to be monitoring how long they are spending at each table, which may interfere with their ability to contribute productively to discussion. Other commonly discussed challenges include homework grading and student frustration with tutorials.

Likewise, we have observed instances of TAs recognizing instructional strategies that they are still trying to improve. For example, Oliver described in an interview that he knew Socratic dialogue was important, but felt he needed more practice to do it better. As TAs in this setting are expected to use Socratic-style teaching but do not receive ongoing training in how to use it effectively, targeted discussion (for instance, during the weekly prep sessions) centered specifically around Socratic dialogue could help TAs like Oliver engage in this practice in a more consistent manner in the classroom.

Metaphors for teaching

We have observed that TAs often use descriptive analogies to talk about how they view their roles in the classroom. In helping TAs refine their beliefs about teaching, it may be productive to leverage and build upon the analogies that TAs already find familiar and relevant. For example, we have already considered how Darren persisted in using a "translating" metaphor for teaching throughout the Fall 2011 semester. Since this is appears to be a particularly salient analogy for him, a useful activity for him and other TAs could be to unpack these analogies to consider the specific features they consider important. (We do not argue for a single "correct" metaphor, but rather the use of metaphors as anchors to discuss components of pedagogical beliefs.)

6.4 Future directions

6.4.1 Survey design

Qualitative coding by hand is time-consuming and limits our ability to consider a large population of TAs at once. Therefore, a productive next step in continuing this work would be to design and validate a short-response or multiple-choice survey that addresses the content of the TA-PIVOT framework. Adams and Wieman [11] document this process for a survey of expert-like thinking, and recommend conducting early interviews to identify effective questions that elicit varied and detailed responses. Based on the interview data we've collected, the protocol in Appendix A could be adapted to an open-ended survey. The FASCI survey [12], due to its open-ended nature, could also serve as a useful model in this process.

6.4.2 TA self-coding

Although the TA self-observations we have described provide useful contextual information, an important methodological step to further apply the TA-PIVOT framework would be to have TAs code themselves. This step would not only provide an additional validational check on the robustness of our coding schema, but could also serve as a more focused reflective activity for the TAs. In this way, we envision the TA-PIVOT framework serving a similar role to the RTOP in teacher professional development.

6.4.3 Impact of environment

A remaining question in this research is the impact of the teaching environment on TAs' beliefs and practices, and the degree to which the support and/or constrain their instructional practices. With further refinement of the framework and interview protocol, we may be able to untangle "splits" in TA beliefs; in other words, which descriptions of a TAs' practices are reflective of their actual models of student learning, and which reflect course expectations that they are upholding but do not necessarily agree with. It would be particularly interesting to follow TAs as they move between teaching in different course environments (such as discussions versus labs) to see whether different course structures constrain their observed practices and, in turn, the coordination with their stated beliefs. Indeed, we may hypothesize that observing TAs in a less constrained environment (in which they have the opportunity to engage in broader decision-making regarding classroom content and organization) will provide a more robust understanding of their practices.

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Appendix A

Interview Protocol

Pre-semester only:

- Do you have any prior teaching experience?
- What were your undergraduate physics recitations like? What were your physics TAs like?
- How would you describe how you learn best?
- Why did you decide to go into physics?

Mid/post-semester only:

- How are things going?/How did the semester go?
- What is teaching, to you?
- As you see it right now, how would you describe your role as a TA?
- If you had complete freedom to create the ideal environment for learning physics, what would it look like?
- What do you think students should learn in a first-semester physics course? Do you think everyone should learn physics?
- Based on what youve seen of the Tutorials, what about them do you think is good for students? What about them would you change?

- How do you think group work is helpful for students? Do you think its helpful for all students?
- Walk me through one of your sections.
- How do you decide to start interacting with a group of students?
- When you do, how does it start?
- How do you know when to leave a group and move on?
- At the beginning of the section, does the TA need to give any sort of introduction to the Tutorial, or just have students get started?
- Is there any experience this semester that stands out to you?

Appendix B

Internal Review Board Approval

University of Colorado at Boulder
Office of the Vice Chancellor for Research
Office of Research Integrity
Human Research Committee
FWA00003492

CERTIFICATE OF HRC REVIEW: EXEMPT

INVESTIGATOR:	**PROTOCOL NUMBER:**	**ADDRESS:**
Dr. Noah Finkelstein	0809.10	Department of Physics, 390 UCB
PROTOCOL TITLE: Video recording of TAs & LAs in introductory physics classrooms to study educational practice over the course of a semester.		

APPROVAL DATE:	**REVIEW TYPE:**	**NUMBER OF SUBJECTS:**
09/17/09	Exempt	100

The Human Research Committee (HRC) has reviewed this protocol and determined it to be of exempt status in accordance with Federal Regulations at 45 CFR 46.101(b) under Exempt Category 1(b) – Educational Practices. Exempt status means that your protocol does not have to undergo further review by the HRC. However, if you make any changes to your research or an adverse event occurs then the HRC must be notified.

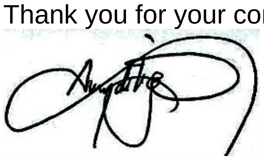
If your protocol changes and exempt status no longer applies, the change(s) must be submitted to the HRC for review and approval **prior** to their implementation.

Please inform the HRC upon completion of this protocol in order for us to maintain our records.

The Human Research Committee has reviewed this protocol in accordance with federal regulations, university policies and ethical standards for the protection of human subjects. In accordance with federal regulation at 45 CFR 46.112, research that has been approved by the HRC may be subject to further appropriate review and approval or disapproval by officials of the institution. The investigator is responsible for knowing and complying with all applicable research regulations and policies including, but not limited to, Environmental Health and Safety, Scientific Advisory Committee, Clinical and Translational Research Center, and Wardenburg Health Center and Pharmacy policies. Approval by the HRC does not imply approval by any other entity.

Please feel free to contact me at 303-492-1940 or by email at amanda.whitson@colorado.edu if you have any questions about this approval or about HRC procedures.

Thank you for your concern for human subjects.



Amanda Whitson,   Date: 09/18/09
Enclosure

Appendix C

Sample Coded Video & Interview Excerpts

Agency
Goal
Assessment

Video

		Dialogue	Action	Codes
1			[TA approaches a table where S1, S2, S3, S4 are seated.]	
2	**TA**	Are you at a point--are you ready to go over some of this yet?		AG2 (Recapping)
3	**S3**	Can we go over A really quick? I think we're on the right track. We think the first sentence is correct.		
4	**TA**	OK, so that's just saying that--	[leans in to look at S3's book]	AG2 (Recapping)
5	**S3**	the smaller mass will have greater velocity.		
6	**TA**	Sounds good.		AG1 (Pass judg)
7	**S3**	But then we said that the second sentence we don't necessarily agree with, because we don't really know how the masses are related to each other, like if this one's actually 100 times smaller, or…		
8	**TA**	Okay. We'll let… well, I guess, keep going. I just want to hear what you have to say.		AG3 (Elicitation),
9	**S3**	Well, I guess to finalize that, and then we don't really know the velocity between each one, because one could have a lot smaller velocity than the other. So we just don't know how it balances out.		
10	**TA**	So one thing we do know is that the velocity of C increases faster by some factor.		AG1 (Cuing)
11	**S3**	Right, because we know acceleration.		
12	**TA**	So how much longer--or how do the times it takes to get to the line compare?		AG2 (Informed cuing),
13	**S3**	Well, smaller--shorter time period for the smaller mass.		
14	**TA**	So it's had smaller time to accelerate. So we don't necessarily, like, if the acceleration is twice as big for C, we don't know that velocity is twice as big necessarily. It probably wouldn't be quite twice as big. So yeah, that seems consistent with what you were saying.		AG1 (Explanation), AG1 (Pass judg), GK3 (Reflection), GE2 (Chaining) AQ1 (I-R-E)
15	**S3**	Okay. Yeah.		

16	**TA**	So what did you think about the kinetic energies of the two?		AG3 (Elicitation), AQ2 (Open-ended)
17	**S1**	They're different, but we can't tell which one's greater and which one's less because we don't know how much…	[moves hands alternately up and down]	
18	**TA**	So how do you know they're different?		AG3 (Ext. reasoning), GE2 (Reasoning), AQ2 (Open-ended)
19	**S1**	They both have different masses and different velocities.		
20	**TA**	Okay, but what do we know about the work done?		AG1 (Pass judg), AG2 (Informed cuing), GK2 (Concept), AQ1 (I-R-E)
21	**S1**	The same.		
22	**TA**	And we had this work-kinetic energy theorem. So if we just look at that, it seems like the kinetic energies ought to be the same.		A1 (Cuing), GK2 (Concept), GE1 (Answer-making)
23	**S4**	The change in kinetic energy should be the same.		
24	**TA**	Right. So if they start at zero velocity.		A2 (Recapping)
25			[S1 erases a previous response.]	
26	**S3**	And it's zero kinetic energy.		
27	**S4**	So the final kinetic energy should be the same.		
28	**TA**	Right. So is that consistent with what we were talking about? We don't really know a whole lot about… I guess you could work it out carefully, but it's sort of not sort of very easy to see		AG1 (Explanation), GK3 (Reflection)
29	**S4**	Yeah. Yeah.		
30	**TA**	And that's why we do this work-kinetic energy thing, is because it makes a really simple way to solve some problems.		AG1 (Cuing), GK2 (Strategy), GK3 (Projection)
31	**S4**	Okay. So the kinetic energies are the same. [to TA] Right?		
32	**TA**	Right.		AG1 (Pass judg)
33	**S4**	Because the net work is the same, the change in kinetic energies are the same.		

34	TA	And what you guys were thinking about was right, it's just it's hard without knowing specifics to say exactly what the velocity and mass relationship is, but it should work out to be this exact same answer. Looks good.		AG1 (Explanation), AG1 (Pass judg), AG2 (Recapping), GE1 (Confirming result)
35			[TA leaves the table.]	

Interview excerpt

How would you describe the job of the TA?	
Well, you're facilitating their discussion. So if they were to just do the tutorial, they would get through it but they might still have lingering questions or they're not sure, or they might have only thought about it one way or have been slightly off in their way of thinking. So I guess your role is to answer questions they have, or either confirm or correct ideas they have about what they're doing. You can do that by getting them to see the logic behind it, whether their reasoning is good or not. So I would say that the role of the TA is kind of answering questions, or asking questions to answer questions. Yeah, just to sort of—or provide a new way of thinking about something. Like if they finish it really fast too, you can try to get them to have a deeper understanding of it.	AG3 (Let students discuss) AG1 (Explaining) GE2 (Reasoning) AG2 (Socratic questioning)
How do you think the TA's job is different from that of the professor?	
Well the professor like presents the material the first time. So I guess they have—they just have a responsibility to present it in a clear way so the students can like understand it as they see it, but they don't really interact with the students individually as much. So I think the role of the TA is to make sure that a motivated student who didn't necessarily understand the explanation in the lecture can have their questions answered, and has full opportunity to completely grasp the material.	AG2 (Individual attention)
Tell me about working with LAs. How do you think it went?	
It was pretty good. It's nice to have another person there. Like, everyone explains it differently, and some people respond differently to different types of explanations. So it was nice to have someone else there who could—first of all, because there's enough students, you kind of want someone else going around just to give people enough attention. I think it's nice too to have more than one personality in the classroom, so that—it just makes it a little more fun for the students. Yeah, it was good. They all knew what they were doing, and were good at it.	AG1 (Explanation) AG2 (Individual attention)
Do you think the LAs role is different from TA's role?	
I don't think it's very different, at least not in the tutorial itself. Like the TA clearly has to do things with grading and answer questions about that, but for the most part I think our interactions with the students is fairly	

similar. I'm trying to think if there's any way to say they're different. The LAs are a little bit more of their peers, but I don't know if that registers to the students or not all the time. But as TAs, like, I'm not that much older than them either. (laughs) *What do you think of the tutorials?* I think they're for the most part helpful at deepening their understanding of the relevant physics. I feel like a lot of the students thought so too. One frustration some people voiced was that they didn't always have them before the CAPA on the same material, so some people told me that they felt like they understood it after going through it in the tutorial, but it would have been a lot more helpful had they understood it before they had to do problems. It seemed like it really did work, like after we did a tutorial, they got those concepts on the homework. Sometimes it took a little while, like on Newton's Second and Third Laws, it took a little while but you could see the progression of understanding happening. Like people just got more used to the concept and the intuition deepened, and questions that were hard they knew how to answer after that. So that was really good to see. And this semester, one thing we did slightly differently than last semester was an extra tutorial on the forces, and it really helped them be able to draw forces and free-body diagrams, do the third law pairs and that kind of thing, so clearly it's helping. *I think they skipped Tension last fall.* Yeah, something like that. Sometimes the questions aren't always that clear when you first read them, but it's not that too big of a problem if you just go and answer questions about it. I don't think that poses too much of a problem. Yeah, if they're really quick, or if there's one page with not a whole lot to ask about, you just check it and you have to move on. But that's not necessarily a problem, that's just the nature of different parts of a problem being more complex than others. *Anything else that you think is good about the tutorials for students?* Well a lot of the research has shown it's really good for them to work in groups. And I think that's really true. They get to know each other personal, so they can work together on problems and try to answer each other's questions. Yeah, I think that is a good thing. Also, I think they help expose some peoples' weak areas of understanding that they didn't know they had before. So I had some students, they were trying to work really fast and I would go back, and there would be this gap in understanding that they wouldn't have necessarily known about. And so we would go over that, and they'd be like, "Oh! Oh, okay. That makes sense." (laughs) So I think, like, one person in particular seemed like he didn't really want to be there and was just trying to get through the tutorial really fast, but it was helpful when we actually found some little gap there and he would be like, "Oh, okay, that's good to know." So, that was useful.	GK2 (Conceptual) GK2 (Physical intuition) AF1 (Homework/exam) AF2 (Abilities) GK2 (Conceptual) GK3 (Procedural) AQ1 (Checking off) AG3 (Student collaboration) AG3 (Student collaboration) GE2 (Making connections)

What don't you like about the tutorials or think could be different?	
I don't really know how to change the tutorials, or make them better. I think one thing—some people are frustrated in that they do the tutorials and it deepens their intuition but it doesn't necessarily show them how to solve a lot of the problems they have to solve. So some people who were doing well on the tutorials were still having a lot of trouble on the exams and just getting the CAPA done, that sort of thing. I don't know if there's a way to do that in a tutorial, because I think what the tutorials do in getting people to work together and deepening intuition is really important. But I think there's a little bit of an unmet need in showing some people how to answer these questions or how to go about starting them. Or finding ways to do that. And I don't really know exactly how I would change things to make that happen.	GK2 (Physical intuition) GK3 (Problem-solving) AG3 (Student collaboration) GK2 (Physical intuition) GK3 (Strategy)
In a more conventional recitation a lot of it's spent on problem solving. Like, that doesn't—and so you pick up some things on how to solve problems, but then you maybe miss a lot of this intuition and the physics. And clearly it helps people on the homeworks and things, so I know there's value in that. That's the one thing I think is a little bit lacking.	GK2 (Physical intuition) AF1 (Homework)
So you're talking about being able to start and solve a physics exam type problem.	
Or just because they have to do that for the exams and things, or they just read a problem and they're like, "I know about these concepts, but I have no idea how to connect it to a problem, or what to look for in this problem that tells me what concepts I need." And some of that might be they need to get used to doing that kind of problem and it will come as they take more physics classes. I think that was difficult for some students.	GK2 (Making connections)
Walk me through one of your sections. How do you usually start class, and where does it go from there?	
I would usually write things on the board that we had to. If there was anything coming up I would announce it. I would usually announce what tutorial we were doing, but people would often just start on their own. That was mostly it. I don't think I ever really worked out problems in front of the class this semester. I did that a little bit last semester, but there wasn't—I didn't feel like there were as many times when I saw on the homework everyone really missed this concept, so I wanted to present it. I would usually just get people started, and if someone's working on their own, have them join another group. That was mostly it. Usually I would wait a little bit until people had gotten started, usually not until they'd finished the first page, and then I would ask them about it. Usually after they'd finished the next page, we'd just sort of go over that page. Sometimes you just go around and ask, "Is there something you finished you want to go over yet that we haven't talked about?" Often there was, or "Oh no, I already talked about it with so-and-so."	GK3 (Student collaboration) AQ1 (Checking)
So your first round of questioning is usually asking them if they have	

questions…? Yeah, or in the beginning I would sometimes ask… like if I knew it was at a part that was potentially confusing, at least in the problem setup, I would just ask, "Does it make sense what's going on here?" Especially if they haven't really done it yet, I would just make sure they know what they're doing and then wait until they'd finished. But usually if they had finished a section, I would be like, "Oh, can we go over this now?" And then it would be more me asking them questions. Yeah, especially if they're just starting something, I would go around and just ask them if they understood it… but not necessarily ask them anything else right away.	AQ1 (Checking) AQ1 (Checking)
When you interact with students, how does it usually start? Do you usually start, or do they? It would depend on the group. There were a bunch of people who would routinely if they had a question, they would just wave me over like, "Oh, can you help us with this?" But sometimes it would be, I would say, "Oh, it looks like you finished this section, do you mind if we go over that real quick?" And then we would do that, I would try to ask them some of the answers, especially some of the main points, or the harder questions to make sure they understood that.	AQ1 (Checking)
How do you know when to leave a group & move on? Oh, that's a good question. Sometimes it was pretty quick just because they pretty much got it and then I just wanted them to continue so they could discuss it among themselves because it seemed like it was going well, and it wasn't really going to help anything if I just asked them to repeat it more. So then I would just move on. But sometimes they have a misunderstanding so you have to like, try to go over it more. Sometimes it wasn't completely clear when to, because sometimes you want to make sure they have the concept down, while other times the tutorial goes over it a little more, so then in that case I would often just say, "Ok, so it looks like you're on the right track, and if it's not completely clear, it might be soon, and if it's not then we'll talk about it then." So it just depended on the rest of the tutorial and how deep the misunderstanding was.	GE1 (Correctness) AG3 (Let students discuss) GK2 (Conceptual) AG3 (Let students discuss)
At the end of your sections, how would you usually end class? I wouldn't really say a whole lot, usually if there was anything I might say like, just remind them of the homework for next week, and that's pretty much it.	
Do you think you got better at asking questions as the semester went on? I think so, you get used to what sort of questions will actually be helpful. I think I know a little better about when to stop asking questions too, because sometimes they understand it fairly well and if you try to push it deeper, it's just going to become confusing again and you'll sort of undo a	AG3 (Let students discuss)

little bit. So at a certain point it's good to stop and then maybe the next part of the tutorial will bring up some of that, and then you can talk about it. Or when groups are finishing really fast, I thought it was a challenge to try to come up with some other more interesting question to ask them to make sure they really get it and just keep them interested at the end. I definitely got better than the beginning of last semester, just getting used to what is helpful and what isn't.	AF1 (Challenge questions)
Do you think you learned anything else from being a TA?	
Well, there's a lot of just having to come up with, a lot of thinking on your feet to come up with ways of explaining things. Cause there's going to be times when you explain something and it's perfectly clear to you but it's not clear to anyone else. Or this particular group just aren't quite thinking that way. It just made me think I have to try to approach it in different ways, after having been in physics for a long time now, you can look at a problem from different angles than someone who's just started. Especially in the Help Room for a class that I wasn't TAing, so I hadn't already thought about doing the problems. Or like, someone from 2010 maybe who, like, I couldn't explain the harmonic oscillator using derivatives, because it's not the calculus-based class. So I'd have to think, "How else—what is a simple, clear way to do this?" Like, based on what they would know. So I think that was kind of fun, a fun challenge to have to do. It definitely also shows, teaches you something about how people learn, again learning what kinds of questions are actually helpful and when to stop, what depth of explanation is helpful at this point and trying to gauge that based on peoples' responses. Yeah, it was really gratifying when people were like, "Oh, I really get this now, it makes so much sense!" And other times the looks become more glazed and it's like, (weak voice) "Oh, I should stop." (laughs) Yeah, that was definitely helpful.	AG1 (Explaining) AG2 (Individual needs) AG3 (Let students discuss) AG2 (Individual attention) AF2 (Behaviors) AG3 (Let students discuss)
You were saying it was teaching you how people learned. Can you say more about that? What do you think you learned about how physics students learn?	
I guess, just knowing what concepts are pretty intuitive and what concepts aren't. Like, I wouldn't have guessed at the beginning of last semester that people would have so much trouble with force diagrams, just because that seemed so intuitive in my head. But I sort of forgot what kind of concepts were intuitive and what weren't, and what ways of reasoning are helpful to get people to remember that, or what is intuitive. Like when we did pressure this semester, one thing that was helpful was, for understanding that it only depends on depth, is so if you dive down to the bottom of a swimming pool, you know, it really hurts your ears, and it doesn't depend on what the sides of the pool looked like, or how wide the pool is, it's just how deep you go. So that was very helpful for people. In general, just to, "Oh that makes sense, I can remember that." Just getting a better idea of what is intuitive and what isn't. That's mostly what I meant.	GK2 (Physical inuition) GK3 (Strategy) GE2 (Reasoning) GE2 (Physical inuition) GK2 (Physical intuition)

Appendix D

Classroom Norms

In this thesis we have focused solely on the *TAs'* practices, but we cannot ignore the students as participants in the social interactions under consideration. Previous work has indicated that students perceive differences in classroom norms, as measured by their responses to end-of-semester surveys (Turpen 2010). Smaller section sizes limit our ability to discern statistical differences between TAs on such surveys, yet a closer examination of student interactions in these episodes yields evidence that the ways in which TAs engage students in the classroom influences how these students perceive their role in interacting with one another and with the curricular materials. Although we did not go through and code student practices using the TA-PIVOT framework, during the coding process we observed a few notable instances in which student participation appears to be influenced by particular TA practices, which we will comment upon here.

As an example, consider the following episode of Caleb's from Week 7, "Work & Changes in Kinetic Energy":

S1: So we say they're both positive work because they're like, moving in the same direction as the forces.

Caleb: Say that last sentence again?

S1: That they're positive work because they're—the force is in the same direction that they're moving.

C: OK. Cool.

S1: . . . for both of them.

C: Does that make sense to you guys?

S?: Yeah.

S1: We all agreed on that one.

C: But the forces are opposite signs.

[Some halting student statements]

C: Wha—Say that again, [S3]?

S3: They both have positive work. . . that's what's screwing us up.

S5: No, because the, um. . .

S4: Even if you do look at it in the single coordinate system—

C: (to S5, putting a hand on his shoulder) Say that out loud.

S5: Because the force is negative this way, and then the displacement is also negative. . .

S4, S3, S2: It's positive.

C: Right on. [S4], forgive me for interrupting you.

S4: No, that's fine. *[Points to S5]* That's what I was exactly going to say.

C: That's what you were going to say?

S5: Yeah.

S4: (to S5) That's exactly what I was going to say.

S5: *[Offers a high-five to S4]* Good job, man.

S4: Teamwork.

C: (indicating S4 & S5) Excellent. I love this camaraderie.

To begin with, we observe several specific moves Caleb makes to emphasize student agency in this episode. First, he notices S5 being interrupted in the middle of making a productive contribution, and in Line 17 makes an explicit bid for him to complete his thought. Lastly, he calls attention to the "camaraderie" displayed by S4 and S5 (Line 28). Discursive moves such as these reinforce the collaborative nature of the activity, which is in turn picked up by the students in celebrating the fact that they reached the same conclusion.

Again, Caleb's students (a different group than the previous episode) provide an additional example of this, also during Week 7:

> **Caleb:** So what they would like to know is, can you just multiply the net force by the net displacement? [pause] Do you have to do each one individually and then sum those up? Right? Is like, kind of, uh, is the product of the sums the same as the sum of the products? Like kinda, that kinda thing. So you don't need to write a mathematical answer for this. You can say, y'know, find the total displacement and then calculate work. Or you could say, calculate work for each individual force and displacement, and add. Or something like that.
>
> S5: Is it that one, or is it the one before?
>
> **C:** Well, what do you think, [S5]?
>
> S5: The second one.
>
> **C:** Yeah? Why?
>
> **S5: Yeah, but we're not in consensus here.**
>
> **C:** Oh, well let's have a discussion! What a perfect—
>
> S5: That's why we called you over!

In this excerpt, S5 appropriates Caleb's focus on establishing consensus as a goal for their group. (Notice that she specifically refers to "consensus," instead of saying, "We don't agree," for instance.) However, this interaction does not make it clear whether the students persist in seeking consensus in the absence of the TA; further examination of student discussion would be needed to ascertain this.

We also observed instances of students reacting *against* TA instructional practices. Contrast the preceding episodes with the following excerpt of Terrence interacting with a group of students, again during Week 7:

Terrence: Hey guys.

S3: Oh god.

T: Oh god?

S3: Nah, I'm just messin'.

T: You always sound scared when I come by.

S4: That's 'cause you confuse people with your questions [?] and we don't take pleasure from it.

S2: It's true. And you don't give any like positive feedback. It's always just like, "Are you right? Are you right? I don't know, is it right?"

T: Well, I'll tell you, I never leave the table until I know you guys have it right.

S4: Well yeah.

S2: Alright, so I'll take that as a, as a, "We're right."

T: (laughs)

S2: —Instead of any positive feedback.

This exchange is notable because Terrence's students actually confront him about the intimidating nature of his teaching style, as well as the lack of positive feedback he provides. Terrence responds to this by assuring the students that he would not leave them with an incorrect idea (which he also stated during an interview). In this dialogue, the often tacit goals that underpin TA actions are briefly made visible.