ABSTRACT

Title of Document: INVESTIGATING AND ACCOUNTING FOR PHYSICS GRADUATE STUDENTS' TUTORIAL CLASSROOM PRACTICE

Renee Michelle Goertzen, Doctor of Philosophy, 2010

Directed By: Research Assistant Professor Rachel E. Scherr, Department of Physics

Professor Edward F. Redish, Department of Physics

Physics Education researchers have been working to understanding how students learn physics, which has led to the creation of a body of research-based curricula. It is equally important to study novice instructors, graduate teaching assistants (TAs), who often teach these students. The study of TAs has similarities to how students have been studied: it is important to identify what preconceptions they often enter the classroom with, what resources they may have that they could apply to their physics teaching, and how both the classroom environment and past experiences affect what they are doing in the classroom. Although TAs are responsible for a significant portion of students' instruction at many universities, science TAs and their teaching have not been the focus of any significant amount of study.

This dissertation begins to fill this gap by examining physics graduate students who teach discussion sections for introductory courses using tutorials, which are guided worksheets completed by groups of students. While assisting students with their conceptual understanding of physics, TAs are also expected to convey classroom norms of constructing arguments and listening and responding to the reasoning of others. Physics graduate students enter into the role of tutorial TA having relative content expertise but minimal or no pedagogical expertise.

This analysis contends that considering the broader influences on TAs can account for TA behavior. Observations from two institutions (University of Colorado, Boulder and University of Maryland, College Park) show that TAs have different valuations (or buy-in) of the tutorials they teach, which have specific, identifiable consequences in the classroom. These differences can be explained by differences in the

TAs’ different teaching environments. Next, I examine cases of a behavior shared by three TAs, in which they focus on relatively superficial indicators of knowledge. Because the beliefs that underlie their teaching decisions vary, I argue that understanding and addressing the TAs individual beliefs will lead to more effective professional development. Lastly, this analysis advocates a new perspective on TA professional development: one in which TAs' ideas about teaching are taken to be interesting, plausible, and potentially productive.

INVESTIGATING AND ACCOUNTING FOR PHYSICS GRADUATE STUDENTS' TUTORIAL CLASSROOM PRACTICE

By

Renee Michelle Goertzen

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2010

Advisory Committee:
Professor Edward F. Redish, Chair
Research Assistant Professor Rachel E. Scherr, Advisor
Professor Spencer A. Benson
Professor Thomas D. Cohen
Research Assistant Professor Andrew Elby
Professor David Hammer

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grants No. REC 05-29482, and No. REC 0715567. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

I have been fortunate to have two excellent advisors. I was privileged to work with such a talented advisor as Rachel Scherr. I could not have asked for a better role model. I am particularly grateful for Joe Redish's guidance and encouragment during my early years at graduate school. Working with Rachel and Joe has been both intellectually rewarding and inspiring.

I am also grateful for the chance to work with many exceptional people in the Physics Education Research Group and the Science Education Group at the University of Maryland, College Park: Saalih Allie, Leslie Atkins, Luke Conlin, Brian Danielak, Ben Dreyfus, Andy Elby, Brian Frank, Paul Gresser, Ayush Gupta, David Hammer, Ray Hodges, Mike Hull, Paul Hutchison, Steve Kanim, Eric Kuo, Matty Lau, Tim McCaskey, Rosemary Russ, Tiffany Sikorski, Elvira Stanescu, and Jonathan Tuminaro.

Heartfelt thanks to my family: Andrew, Gerry and Bernice, Shawn and Stacey, and Kyla and Bryce.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

The physics education community has a significant knowledge base regarding how people (that is, students) learn physics. In the process of doing that research, we have identified a variety of things that are important to pay attention to: what ideas and knowledge students bring into the classroom, what resources they might already have from past experiences, and how the minute-by-minute interactions they have in the classroom (with their teachers and with each other) affect what they think is appropriate behavior in the classroom. Physics TAs also deserve study, because they are often instructors for a significant portion of the students' class time. Little research has been done on physics TAs. We can begin by exploring the same topics that we already know matter for physics learning, but now with the aim of understanding physics teaching. For example, physics graduate students enter the classrooms they'll be teaching with beliefs about what it means to teach and learn physics, usually based on their own past experiences. They have experiences they can apply to teaching physics, either from formal teaching (or tutoring) or because of the physics learning they have done in groups as undergraduate students.

This work provides a foundation for TA research by providing evidence for several big ideas:

- TAs' attitudes about teaching are affected by the environment in which they work, from the type of classroom they teach in all they way up to the meta-messages they receive from other professors and TAs about the importance of and correct methods for teaching physics.

- TAs who value the materials they teach are more likely to convey these values to their students.
- TAs can share classroom behaviors that look similar, but these behaviors can be supported by beliefs and motivations that vary by TA as well as by context.
- We can benefit from understanding TAs' ideas and beliefs as they begin teaching, in order to take them into consideration when we are trying to convince them to teach in a new way.
- When TAs participate in professional development, they should be treated as partners in the endeavor of educating students.

1.1 Motivation

My work focuses on TAs teaching tutorials. These are physics graduate students, often in their first or second year of graduate school, who are instructors for the discussion sections of introductory physics classes that use guided worksheets (tutorials) to structure group learning instead of the more typical problem-solving discussion sections. I explore TA behavior at many different levels. For example, I analyze the beliefs, knowledge, and expectations that TAs draw on at a minute-by-minute level when interacting with students in their classrooms – an analysis that involves just one group and TA at a time, interacting for periods of just a few minutes. Another analysis takes place at a broader level, concerning how the classroom and departmental environment in which TAs work affects how much they support the reform curriculum they use in their teaching.

The ultimate goal of research such as this is to create and implement more effective TA professional development (PD) for physics graduate students teaching reform curricula. As I discuss in more detail in chapter two, physics departments and TA instructors have an opportunity to significantly affect physics instruction through the professional development they offer to physics graduate students. For example, a University of Maryland TA may teach one or two hundred students during a semester, and these students often spend between one quarter and one half of their physics contact hours with their TAs. During this time, the TA has the opportunity to affect not just what content these students learn, but also their understanding of what it means to learn physics. Moreover, some of these TAs will become professors once they graduate, and their jobs as TAs may be their only significant teaching experience. Thus, TA professional development can be a chance to immediately improve undergraduates' learning and epistemological beliefs about physics as well as a chance to affect physics instruction in future decades. The research presented in this dissertation will hopefully serve as a starting point for the development of more effective TA PD.

1.2 An introduction to TAs

Graduate student teaching assistants are students, teachers, and apprentice researchers, and their roles vary depending on the context in which they are acting. As beginning researchers, they are supported by their advisors and other faculty. As physics students, they are often considered to be experts. (Although in some cases their physics knowledge may be less than perfect (McDermott, 2001; McDermott, Heron, Shaffer, & Stetzer, 2006), in most cases their students view them as experts in the subject and the TAs themselves frequently expect that they should have mastered introductory material.) As instructors, however, most are novices. It is common for a first-year physics graduate student to be placed in charge of a discussion section or laboratory with only a few hours or days of training. Because they have limited teaching experience and limited training, they are likely to draw on their past experiences as a student of physics to inform their teaching. For that reason, we review a typical pre-graduate-physics-student experience here.

The undergraduate physics culture that shapes many physics graduate students is distinctive, with its own norms and expectations. In his ethnographic study of physics undergraduates at a large research university, Nespor (1994) characterizes the physics undergraduate program as one that monopolizes students' time from their first year, tightly constraining their activities and personal associations so that success depends on immersing one's self into study groups with other physics students and avoiding too much time spent on family or other social events. Physics undergraduates across various institutions usually study from the same small set of accepted textbooks and use a relatively standard undergraduate curriculum that prepares them for the relatively standard curriculum across graduate schools in the United States. In other words, a student graduating with a physics undergraduate degree does not simply possess knowledge about physics; she has been shaped to become a physicist, which usually includes acceptance of the physics' community's values.

While the past experiences of various graduate students vary, they have all chosen to become professional physicists, and as a result, have begun to absorb the norms of the discipline of physics. The graduate students who are accepted by the University of Maryland (UM), a Tier 1 university with a large and prestigious graduate program, are likely to have worked particularly hard as undergraduates in order to achieve the high grades and test scores required for acceptance to UM.

The cultural practices that graduate TAs absorbed when they were undergraduates influence what they consider appropriate when learning and teaching physics. For example, most graduate students learned in a traditional manner and they have learned how to successfully learn when material is presented in lecture form. They might think that students who have trouble learning in such a manner are either unmotivated or just not “cut out” for learning physics. Likewise, physics graduate students have taken mathematically intensive classes, and they have learned to value the role that mathematics plays in physics, which might make them feel like physics courses relying on conceptual reasoning are not exposing students to the full beauty and usefulness of physics. These cultural practices shape what graduate TAs value, and can also exert an influence on what they do in the classroom.

1.3 Dissertation structure

The data analysis chapters in this dissertation are a compilation of three papers that were written for publication. Chapters Four and Five have already been accepted for publication, and Chapter Six has been submitted for publication. These chapters were written with co-authors and have not been substantially altered from their published form. Thus, each contains a literature review, theoretical framework, and conclusions that are specific to that chapter. In addition, the dissertation connects these chapters and places them in a larger context with a literature review (Chapter Two) that places TA research overall in a larger field of research and a theoretical framework (Chapter Three) that describes my general explanatory framework for interactions and cognition.

1.3.1 Chapter Two: Past research relevant to the study of tutorial TAs

This chapter begins by reviewing research on graduate student TAs in the STEM (science, technology, engineering, and mathematics) disciplines. It describes various types of professional development that have been offered to STEM TAs, as well as how the effects of those programs have been assessed. I then discuss the classroom practice that professional development aims to affect. I argue that detailed observations of TA teaching leads to better understanding of the motivations and beliefs that support their practice.

The second half of the chapter reviews a portion of the research on K-12 teachers that can inform TA professional development. I discuss research on various factors that can influence teachers' practice: pedagogical and epistemological beliefs, contextual factors, and pedagogical content knowledge.

1.3.2 Chapter Three: A theoretical framework for explaining interactions and cognition

This chapter introduces the theoretical framework that supports my work as a whole. Although each data analysis chapter depends on certain aspects of my theoretical framework more than others, all the research presented in this dissertation is concerned with generating explanations for TA classroom practice. Thus, I introduce a framework called *framing* for explaining certain parts of what happens when individuals interact. I then summarize two different perspectives on where thought lies, in the mind (cognitivist) or within the interactions of people and their environments (socio-cultural); both of these perspectives influence the analysis in this dissertation. The chapter closes with a discussion of the *resource framework,* which considers whether ideas are appropriate to a given situation rather than being categorically right or wrong. The resource framework shapes the upcoming analysis in two ways. First, I treat beliefs like resources, as varied, context-dependent elements of thought. Secondly, I look for resources that TAs have that could be productive seeds on which to build responsive professional development.

1.3.3 Chapter Four: Accounting for tutorial TAs' buy-in to reform instruction

This chapter examines how TAs value (buy into) the tutorials that they teach. I begin by presenting a case study of a TA who does not buy into particular characteristics of the tutorials. His lack of buy-in influences what he does in the classroom. After I have demonstrated that buy-in has the potential to affect teaching practices, I present a comparison of two groups of tutorial TAs, one at the University of Maryland, College Park and one at the University of Colorado, Boulder. An analysis of the TAs' beliefs (as articulated in their interviews) shows broad differences in their buy-in, both in the types of tutorial attributes they support as well as the amount of buy-in they espouse. I then discuss the differences in the "social and environmental context" experienced by the two groups of TAs, which includes the classroom, departmental, and institutional levels of implementation. I argue that these differences have the potential to strongly influence TAs' buy-in to tutorials.

1.3.4 Chapter Five: Similar teaching behaviors are supported by varied beliefs about teaching and learning

In this chapter, I identify a teaching practice I call "focusing on indicators," by which I mean a TA's acceptance of relatively weak evidence of student indicators. These indicators include key words, diagrams, or the correct numerical answer. I present cases of this behavior in three tutorial TAs and discuss how the beliefs that underlie the behavior vary for each TA. For example, the "focus on indicators" in one case is supported by a belief that a TA should ensure students have the right answer. A similar behavior in a different episode is supported by a TA's belief that TAs should help students work productively in the right direction. Examples like these support the argument that effective TA PD cannot simply target unsuitable teaching practices but also should address the beliefs that guide TAs' teaching.

1.3.5 Chapter Six: A new perspective: Respecting TAs' beliefs and experiences

In this chapter, I advocate for a new perspective on TA professional development, using the same theories that have proved successful with undergraduate physics students' learning. Physics education has learned the importance of respecting the knowledge that students bring to the classroom; I argue that such respect, paid to the naïve knowledge that beginning physics instructors bring to the classroom, can benefit TA instruction as well. I present multiple teaching episodes of a TA named Alan. My initial analysis of these episodes focused on the ways Alan's teaching was not aligned with the goals of tutorials. Further analysis showed that Alan's beliefs were well aligned with what he did in the classroom. When using a perspective that endeavors to respect his beliefs and experiences, I am able to locate “productive seeds” within his beliefs and experiences, upon which more responsive professional development could be based.

1.3.6 Chapter Seven: Summary and future directions

In Chapter Seven, I summarize the findings discussed in Chapters Four through Six. I examine the limitations of these findings, discuss directions for possible future research, and consider implications for TA professional development. I conclude by reflecting on the obstacles that may impede improvement in TA PD and signs of support for the endeavor.

Chapter 2 Past and future TA research: previous research on TAs and the teacher research that should guide future studies

2.1 Introduction

At large research universities, teaching assistants (TAs) play an important role in undergraduate physics instruction: they often lead discussion sections, teach labs, grade homework and exams, and conduct office hours. It is not unusual for introductory physics students to have as many contact hours with their TA as with their professor. And while TAs are not often responsible for determining course content or deciding the types of activities (lecture, problem solving, etc.) in which students engage, they are the people who implement those decisions. The decisions that TAs make have the potential to influence their students' ideas about what it means to learn physics and what the students actually learn. In light of the possible influence TAs could have on large numbers of students, the research on them has been sparse.

The larger purpose of the research discussed in this thesis is to provide information that could lead to improved professional development (PD) for TAs. There are two types of information that could contribute to this improvement: knowledge about TAs' classroom behavior and knowledge about the influences on TA practice. The existing research on TAs has largely focused on descriptions of PD programs and limited assessments of their effects on TAs, usually with respect to how TAs' attitudes or beliefs may have changed. What are still rarer are detailed analyses of TA classroom practice and how both PD and TAs' beliefs and knowledge can affect that practice.

This chapter begins by reviewing the literature on TAs, including descriptions of PD programs, how their effect on TAs has been evaluated, and how TA practice has been analyzed. The second part of the chapter reviews research on teacher practice, focusing on how beliefs, context, and pedagogical content knowledge influence teachers' classroom practice. The literature discussed in this chapter sets the stage for analysis in Chapters Four through Six by providing an overview of literature useful for understanding TA practice. First I review what is known about TA professional development and I argue that detailed observations of TA practice will lead to better explanations of *why* TAs make the teaching decisions they do. I end by outlining some of the ways that researchers have attempted to explain science and mathematics teacher practice, because such literature could inform future TA PD. In addition, some of the analysis chapters include reviews of research useful for that topic: Chapter Four considers how reformed teaching correlates with student thinking and the effects of context on professors' instruction, and Chapter Six reviews research on responsive TA PD.

2.2 Previous research on STEM graduate teaching assistants

Research on TAs falls primarily into two categories: research that considers their job as TAs as one aspect of their role as graduate students and research that concentrates on their participation in professional development (PD) programs. Studies in both categories rarely include the in-depth characterizations of TA teaching practices that I argue are necessary. Studies that have included fine-grained descriptions of TA teaching are considered separately, in Section 2.3.2. Because research on graduate TAs is a small field, this discussion includes research on TAs in all of the STEM (science, technology, engineering, and mathematics) disciplines, in order to consider as much of the relevant literature as possible.

2.2.1 TAs identify past experiences and environmental constraints as effects on their teaching practice

Some researchers have looked at TA teaching as one part of students' overall graduate experience. In contrast to most TA literature, these studies do not attempt to describe or assess professional development that is offered to TAs. Instead, they examine the multiple roles of graduate students, in which they must be researchers and students in addition to instructors (Belnap, 2005; Bucher, 2002; Hume, 2004; Lin, 2008). Because the data mainly comes from the TAs themselves (through interviews or surveys), these studies can help us understand what TAs perceive as influences on their teaching. For example, Lin (2008) found that most of the Ohio State University physics graduate students she interviewed planned to teach as they had been taught and that some reported that their classroom decisions (such as whether to use group work) were constrained by the lecturer who supervised them. Another analysis, motivated by pilot study results that the PD offered to a group of University of Arizona math TAs had a limited effect, identified influences on TAs such as time demands, actions of supervisors, and past instructors (Belnap, 2005). Findings of this sort provide a starting point for research on TA PD, because they identify influences that should be further investigated.

2.2.2 A variety of TA PD programs have been offered

There are a significant number of studies that describe professional development programs offered to TAs (Etkina, 2000; Gilreath & Slater, 1994; Hollar, Carlson, & Spencer, 2000; Lawrenz, Heller, Keith, & Heller, 1992; Price & Finkelstein, 2006; Robinson, 2000; Rushin, et al., 1997). These studies can suggest specific techniques, such as peer observation (Robinson, 2000) or the use of experienced graduate students to lead training workshops (Hollar, et al., 2000). Other studies describe the activities that make up semester- (or quarter-) long courses (Etkina, 2000; Lawrenz, et al., 1992; Price & Finkelstein, 2006).

Lawrenz et al. (1992) is a typical example of descriptive PD research. It describes a mandatory course at the University of Minnesota that prepares physics TAs to lead group problem solving sessions and laboratories. The curriculum included discussions of constructivist theories of learning and the development of lesson plans. The TAs also learned about problem solving by solving problems in a group and then grading sample student solutions. An external evaluator assessed the course by observing TAs teaching, interviewing them, and administering questionnaires. The results of this evaluation, which also compared two cohorts of TAs, were broad and little data was cited to support them. For example, they found that the TAs in the second year "appeared more confident in their role as teacher, and there appeared to be more direction and purpose in the lessons." (Lawrenz, et al., 1992, p. 109).

2.2.3 Limited assessments of TA PD suggest positive effects

Some researchers have attempted to measure the effects of their training programs for TAs using surveys, written assignments, or interviews that assess reported changes in the TA's attitudes about teaching or learning (French & Russell, 2002; Hammrich, 1994, 2001; Ishikawa, et al., 2000; Ishikawa, Potter, & Davis, 2001). The studies using surveys have provided glimpses of TA changes after PD, including more appreciation of the importance of attention to student ideas (Ishikawa, et al., 2000), and an increased belief that skills learned while teaching can improve their research (French & Russell, 2002).

A study of this sort, conducted by Ishikawa et al. (2000) at the University of California, Davis, relied on written assignments and a free-response survey to assess the beliefs of two cohorts of TAs before and after a PD course. The researchers characterized common beliefs of the group of TAs as a whole before and after the PD course. Before the course, the TAs described the abilities of a good teacher as those of communicating knowledge, helping students, and motivating students with their enthusiasm. (These results were not separated by cohort.) After the course, the TAs in the first cohort added the skill of being "aware of student learning" as a characteristic of a good teacher; this was the only noticeable difference between the pre- and post-course assessments of the first cohort. The second cohort showed more changes in their conception of a good teacher. They were less likely to relate good teaching to the ability to communicate knowledge and they measured good teaching by the amount of student learning that occurred. An example of a response demonstrating this awareness was one that said, "When whatever you were trying to get into the student's head sticks there, there you are." (Ishikawa, et al., 2000, p. 6). Thus, after their participation in the PD course, TA's responses reflected a change from emphasis on the teacher to an emphasis on the students.

2.2.4 Limited observations of TA practice suggest straightforward categorizations of TA behavior

When TAs' teaching is observed, it is often done to assess the effectiveness of the training they were given (Ezrailson, 2004; McGivney-Burelle, DeFranco, Vinsonhaler, & Santucci, 2001; Pellathy, 2009) or because the observations are part of an assessment for a PD class (Allen, 1976; Etkina, 2000; Roehrig, Luft, Kurdziel, & Turner, 2003).

In the studies that use observations as part of a PD class, the main purpose for the observations is to generate feedback for the TAs, which is shared with them (Allen, 1976; Etkina, 2000; Roehrig, et al., 2003). These studies use observations to provide numerical assessments of the classrooms or general descriptions of what they have learned through their observations. For example, as part of the semester-long course Etkina offered to Rutgers University physics students, she visited each TA's classroom four times. Etkina rated the TA in categories such as "adequacy of wait time" and "assessment of student understanding" on a numerical scale. She summarized her observations with the reflection that, "After three years of observations of more than 20 TAs I have a clear picture of typical difficulties that TAs experience… A universal problem is that the TAs do not understand that every class has a goal." (Etkina, p. 130) The results of the classroom observations are provided as feedback for the TAs, but they are not included in the study; the purpose of the observations appears to be pedagogical rather than for research.

Research that explicitly aims to understand science graduate students' teaching (Calder, 2006; Ezrailson, 2004; McGivney-Burelle, et al., 2001; Pellathy, 2009) has used multiple measures to characterize TAs and their teaching. In these studies, observations are often used to categorize TAs' instruction. For example, Pellathy (2009)investigated the effect of PD workshops designed to improve the pedagogical content knowledge (PCK) of physics TAs at the University of Pittsburgh. He audio taped four TAs teaching discussion sections and coded the transcripts of the classes to determine how often they used different representations (such as analogy, graphs, or mathematics) when teaching problem solving.

As a result of these observations, Pellathy concluded that TAs infrequently used the multiple representations they were taught in their trainings and that they often omit steps needed to understand the procedures. For example, TAs rarely defined the system they were considering when solving work-energy problems. This is necessary because the definition of the system determines whether energy transferred from one object to another is considered internal energy (for a transfer within the system) or work (for a transfer from outside the system). This study's categorization of TA practice through coding allows us to see the relative prevalence of certain types of behaviors, which helped support Pellathy's conclusion that the PCK offered in the TAs' workshops did not significantly affect their teaching.

2.3 Understanding TA classroom practice

The research discussed up to this point provides an introduction to how TAs think about their teaching, descriptions of the PD programs TAs are offered, and an overview of how the effects of these programs have been assessed. These findings are a useful beginning: it is important, for example, to understand what TAs perceive as the influences and constraints on their teaching. One component that could contribute to improved TA instruction is a better understanding of what TAs do in the classroom. In this section, I argue that the research I discussed earlier has not paid sufficient attention to TA classroom practice. I then discuss a study that attends to TA teaching in the way I advocate; the detailed analyses of the TAs' teaching, along with interviews, allows us to better understand how TAs' beliefs affect their teaching.

2.3.1 TA classroom practice has been insufficiently studied

As the TA instructors develop PD programs for TAs, we need a way to assess their effect on TAs. Studies that primarily focus on describing a particular PD program may serve a purpose for other TA instructors who need suggestions for tomorrow's class. Their value is limited, however. If the effects of the program on the TA's teaching and his students are not included, the average TA PD instructor cannot determine whether a suggested training would benefit his TAs. When PD is not sufficiently assessed, we also miss an opportunity to understand the relationship between particular interventions and changes in TAs.

One way to evaluate PD is through surveys and written assignments. Surveys provide a way to assess larger groups of TAs and to identify shared knowledge or beliefs. However, a limitation of analyses built primarily on written materials is that they cannot address the question of how knowledge or beliefs affect practice. This is because the use of self-reported classroom analysis means that researchers may not be able to identify influences that the TAs had not recognized themselves and the TAs' self-reports may not accurately reflect their teaching practices. Multiple studies in math and science education have demonstrated that teachers' self-reports of their behavior and beliefs do not consistently correlate with their classroom actions (Bryan, 2003; Cohen, 1990; Jones & Carter, 2007; King, Shumow, & Lietz, 2001; Levitt, 2002; Simmons, et al., 1999; Tobin & McRobbie, 1997).

As discussed in Section 2.1, researchers have observed TAs in the classroom for the purposes of understanding the constraints on their teaching and to assess the effect of TA PD on the TAs. As an example of the limited descriptions of TA practice found in many works, consider the study of University of Arizona mathematics TAs discussed in Section 2.1.1 (Belnap, 2005). As part of a study to understand why the PD offered to the TAs was not significantly affecting the TAs practice, Belnap observed several TAs in the classroom. The following excerpt is a summary of Belnap's observations of three classes taught by a TA named Lisa.

From the very beginning, Lisa's teaching style consisted of lecture, which she would begin shortly after giving a few announcements or reminders. Initially, this lecture incorporated a cycle of instruction, illustration, and assessment. First, she would provide definitions and explain ideas, then she would show various examples, and finally, she would lead the class through sample problems, quizzing them occasionally for an answer or for single steps in a problem (Belnap, 2005, p. 50).

This characterization gives a general idea of the types of activities one might observe in Lisa's class. However, there are many details that could be included to give a better understanding of Lisa's teaching, such as whether examples and questions are chosen in response to student ideas or how much reasoning was required for an answer to be considered correct. Detailed knowledge about TAs' teaching practices, in addition to detailed knowledge of factors affecting that teaching, is needed to explain how teaching decisions are made. Understanding how teaching decisions are made, in turn, help us understand what TA instructors can do to better support and enable effective teaching practices.

2.3.2 Detailed observations of TA classroom behavior lead to better understanding of the motivations underlying those behaviors

As we have seen, descriptions of TAs in classrooms often characterize their teaching broadly. Fine-grained analyses of TAs' beliefs and practices are one way to better understand what drives their teaching decisions (Seung, 2007; E. Seymour, 2005; Speer, 2001). One such example is a dissertation by Speer (2001), which suggests that typical assessments of instructor beliefs, especially surveys, are insufficient for understanding the individual instances of classroom practice.

Speer studied two graduate mathematics TAs at the University of California, Berkeley who shared two beliefs: that learning mathematics requires problem solving in addition to procedural skills and that mathematics includes learning about ideas and relationships. However, the detailed case studies of the two students, Zachary and Karl, show important differences in their beliefs. These differences only became apparent during interviews in which the TAs discussed video clips from their classes. The use of video-clip interviews placed the TAs' explanations of their actions and motivations within the context of specific examples.

One example of a dissimilarity uncovered through the video interviews is the TAs' beliefs about questioning. Although both TAs thought that it was important to question students, Zachary felt that questions were necessary to check the strength of student understanding and to provide a mechanism for students to learn. Furthermore, when students were unable to answer his questions, he considered this evidence that they did not understand the concept. As a result, his questions were often motivated by his desire to understand the students' difficulties and to help them identify and overcome their problems themselves. On the other hand, Karl asked questions to model the behavior he wanted students to emulate when problem solving and to monitor their learning so he knew when to intervene. Karl looked for situations where he needed to intervene because it was important to him that students not stray too far from the material that he had prepared and that all students complete the same problems. As a result of his corrections, students in Karl's class spent less time exploring why their original answers were incorrect than in Zachary's class. In addition, Karl often assumed that a student's lack of a correct answer was due to low confidence or a momentary "forgetting" of what they already knew. This meant that he had fewer chances to find the inadequacies in his students' conceptions.

These detailed case studies point out subtleties that a survey assessment alone would not have detected and the observations of classroom work provide a way to see how these belief differences about questioning compared to classroom teaching styles. This suggests that surveys that ask about teachers' beliefs, even if they are specific, would be less likely to reveal the finer-grained differences that lead to different teacher behaviors. Surveys might also not reveal the different beliefs that might be activated, depending on the context of the particular situation. The students in Zack’s and Karl’s classrooms had different classroom experiences, but these variations could only be understood though the careful examination of behavior in the classroom.

Past research on TAs has begun to answer important questions about TAs. We have some tentative ideas about what TAs think their job in the classroom is, what they think constitutes good teaching, and some of the general difficulties they face when teaching. We can build upon this, as Speer has done, by examining episodes of TA classroom practice to better understand the actual behavior of TAs in classrooms, what motivates it, and how it affects students.

2.4 Research on K-12 teacher practice as a guide for TA professional development

Considering the limited research on TA instruction and the effectiveness of PD offered to them, where could we look for research to inform the study of science TAs? The natural place to look is at science education's attempts to explain teacher practice, especially novice teacher practice. The application of this literature should be done carefully, however, because while TAs have many similarities to novice teachers, they also differ in important ways.

It seems apparent that there are some differences between TAs and teachers. Teachers have typically had more instruction in educational methods. Because TAs are graduate students, most have more instruction within the discipline they teach, compared to teachers. (While only 33% of physics K-12 teachers have a physics degree (Neuschatz & McFarling, 1999, p. 9), 90% of physics graduate students have a degree in physics or astronomy (Mulvey & Tesyafe, 2006, p. 6)). Each population is a member of a different community, and likely identifies differently: TAs primarily identify themselves as physicists, or physics students, and only secondarily as instructors, whereas teachers consider "instructor" to be a primary part of their identity. The job of teaching also serves a different purpose for each: teachers have chosen to make education their profession, while graduate students act as teaching assistants because it supports their choice to attend graduate school, and they may or may not plan to teach once their schooling is completed.

The similarities between novice teachers and TAs, however, suggest that research aimed at explaining teacher practice can help inform research on improving TA practice. For example, both novice teachers and TAs have little experience in running their own classrooms and must balance the tasks of teaching and classroom management. Both groups are considered experts by their students, yet they both may not identify themselves as pedagogical experts. They both may work with curriculum that they have not chosen themselves. They are both learning how to balance classroom management while creating opportunities for student learning. In addition, while they have spent many years as a student, they may not have much experience in attending to and responding to student thinking.

2.4.1 Teachers' pedagogical and epistemological beliefs may influence their practice

Although we must be careful when using teacher research to understand TAs, it can provide a starting point for understanding their behavior. The vast field of teacher belief literature on teacher beliefs is a good starting point. Because I am interested in understanding what influences the decisions TAs make in the classroom as they teach, I focus this discussion on research that has examined teachers' instruction, through observations or recordings, as well as their beliefs.

One focus of teacher belief literature is on identifying and categorizing teachers' beliefs (Brickhouse, 1990; Southerland, Johnston, & Sowell, 2006), which are often assumed to be a coherent set of beliefs that describe an individual and her behavior. A difficulty with these studies was that this alignment between beliefs and behavior is assumed rather than verified. Other studies go beyond categorization to compare teachers' beliefs to their practice (King, et al., 2001; Lederman, 1999; Levitt, 2002; Simmons, et al., 1999), and find that some teachers demonstrate a strong correspondence between their beliefs and practice but others do not. This apparent conflict between teachers' beliefs and their classroom practice has led to more nuanced examination of belief variability, including explanations that distinguish between professed and enacted beliefs and a consideration of teachers in a transitional period between traditional and reform methods of instruction. In this section, I look at a few examples of how researchers have used teachers' beliefs to explain their practice.

2.4.1.1 Teacher beliefs can support or interfere with implementation of reform curricula

Teacher beliefs can be roughly categorized into three types: *pedagogical*, *epistemological*, and *nature of science*. (Nature of science beliefs are often assessed separately and less frequently, and so will not be discussed here.) Pedagogical and epistemological beliefs include ideas about how students learn, such as by receiving information from the teacher or by making meaning of their own experiences; what the role of the teacher should be, such as a guide, a transmitter of knowledge, or the maintainer of order; and what counts as evidence that students have learned, such as reproducing information or applying it novel situations. Researchers have studied how beliefs influence the implementation of reform curriculum or reformed standards (Cronin-Jones, 1991; Haney, Lumpe, Czerniak, & Egan, 2002; Peterson, 1990; Wiemers, 1990); they have also considered how beliefs shape particular classroom practices, such as teachers' use of questions (Rop, 2002) or how they assess students' prior knowledge (2006).

Cronin-Jones (Cronin-Jones, 1991) presented two case studies of middle school science teachers showing how teacher beliefs that conflicted with the philosophy of a reform constructivist curriculum affected the implementation of that curriculum. Using interviews and classroom observations, Cronin-Jones showed that the two teachers she studied shared beliefs that their students should learn factual knowledge, that they needed repeated drills, and that they required careful direction. As a result of these beliefs, the teachers taught the curriculum in a different way than it was intended. For example, because the teachers believed that students needed a great deal of direction, they often modified the group work activities to be done individually or presented the material through a lecture.

Schoenfeld's case studies (1998) show how a deep understanding of teachers' beliefs (along with their knowledge and goals) can be used to provide a causal story of their individual decisions. In each of the four cases, the teacher's beliefs, knowledge and goals for a sample teaching episode were carefully detailed. A model of the episode was developed which demonstrated how particular goals and beliefs contributed to each action that the teacher took. One example is a case study of a physics lesson taught by Jim Minstrell, a physics education researcher and high school physics teacher. When a student suggests an alternative to the conventional method for computing the mean of a set of numbers, the teacher's belief that physics is a sensemaking activity and that student contributions should be encouraged are reasons why the teacher then gives the class time to discuss the new method. The episode analysis addresses how student moves present choices where the teacher must decide the direction of the lesson. For example, when the student suggested an alternative, addressing it meant a digression from the lesson plan. The teacher could have dismissed it quickly or explained why it was essentially similar to previous suggestions. Instead, his knowledge about how students think about averages allowed him to immediately recognize what the student means, and his belief that it is important to encourage student inquiry caused him to temporarily suspend his plan for the class and pursue the student's idea.

In Chapters Four and Five I give specific examples of how TAs' beliefs influence their teaching, resulting in an implementation of reform curriculum that differs from what the curriculum developers intended. The research reviewed in this section suggests that instructors' beliefs can align with their classroom practice (an alignment also seen in TAs) and thus that successful implementation of reform curriculum depends in part on attending and accounting for TAs' beliefs.

2.4.1.1.1 Teacher beliefs and teacher practice mutually influence one another

The past sections may appear to posit a clear, directional effect from teachers' beliefs to their practice. At times it is hard to tell whether this directionality is a convenience, because it may be hard to examine how both beliefs and experiences interact, or whether there is a tacit theoretical assumption that the primary effect goes in one direction. Some of these studies clearly emphasize that beliefs and teaching experiences interact in an ongoing feedback loop (Aguirre & Speer, 1999; Fennema, et al., 1996; Franke, Carpenter, Levi, & Fennema, 2001; Levitt, 2002; V Otero, Finkelstein, McCray, & Pollock, 2006; Schoenfeld, 1998). In Chapter Three, I discuss the implications of assuming unidirectional effects (such as how beliefs influence teaching) and make a case that beliefs and experience must be considered as two factors that mutually affect each other.

In order to understand how examining the complex interaction between teachers' beliefs and practice has resulted in more effective professional development, consider a group of studies on the implementation of Cognitively Guided Instruction (CGI) (Fennema, et al., 1996; Franke et al., 1998; Franke, et al., 2001). CGI is a professional development program for teachers that helps them learn the purpose of recognizing and utilizing student thinking about mathematics. The training teaches them a theoretical model of children's problem solving abilities and problem difficulties, and helps focus their attention on understanding students' problem solving strategies. In one study of two dozen elementary teachers from schools in and around Madison, Wisconsin, the authors compared the students' conceptual and problem solving abilities to classes of these teachers prior to their three years of CGI instruction (Fennema, et al., 1996). The students' abilities increased for every teacher in every grade level and the majority of the teachers were found to have increased beliefs in the ability of students to do math without modeling algorithms.

The authors describe the process of teacher change in the following way. In the early PD sessions, the teachers learned various ways to categorize math problems, which helped them use a wider range of problems, and they learned ways that students typically solve various types of math problems.

> When they tried out problems with their own students, teachers could see that the children actually invented strategies to solve the problems similar to those discussed in workshops. At this point, there began to be iterative changes in teachers' knowledge, instruction, and beliefs. As the teachers saw that their students were capable of inventing strategies and doing more than they had anticipated, they increasingly made problem solving a greater part of their instruction, the children increasingly solved harder problems and reported their thinking… and so it continued. (Fennema, et al., 1996, p. 431)

This analysis demonstrates that one element underlying the success of the CGI program is the acknowledgement that beliefs and practice must change together in order for the changes to be sustained.

The data and analysis presented in this dissertation do not explicitly address how TAs' beliefs and practice mutually influence each other as TAs develop their beliefs and classroom behaviors. More longitudinal data would be necessary to address this question. However, the analysis of individual episodes describes how TAs' beliefs and practice mutually reinforce each other as the TAs interact with their students. In addition, Chapter Six argues that effective TA PD should include opportunities for TAs to regularly practice what they are learning in their PD courses as they are learning it, and to participate in PD activities that respond to the TAs' beliefs. This argument is based on the success of programs such as CGI, which focus on simultaneously developing reformed teaching and beliefs supporting reform teaching, as well as the analysis in Chapters Four and Five that show how TAs' instruction suffers if TA instructors do not attend to TAs' beliefs.

2.4.2 Contextual factors influence teacher practice

Another way that teachers' behavior has been explained is by examining how the environment in which they work affects what they do in the classroom. These contextual factors, (also referred to as environmental, institutional, or social factors), can both support or impede reform teaching, although past research has focused mainly on issues that interfere with improving instruction. In their review of research on teacher learning, Borko and Putnam (1996) identify obstacles to teacher learning that include discipline- based university courses emphasizing algorithmic learning, school policies providing little free time for teachers to reflect or collaborate, and expectations of parents and administrators. Contextual factors can affect teaching by influencing which beliefs the teachers rely on in a given situation, or by shaping what they think is allowed or possible in their classroom. In particular, researchers have looked at how contextual factors influence how reformed curriculum is implemented (Davis, 2003), whether teachers pay attention to student ideas (Levin, 2008), and whether they focus on procedural or conceptual understanding (Cohen, 1990; Eisenhart, et al., 1993).

Rop (2002) examines how a chemistry teacher's response to student questions varies depending on which beliefs are prioritized, which in turn depend on the context of the questions. The case study, conducted at a Midwestern suburban high school, analyzes the teacher's beliefs (which Rop calls “teacher assumptions”) and his responses to "Student Inquiry Questions" (SIQs), student questions that are content related and arise from curiosity. The teacher, Mr. Kelso, considered SIQs evidence of student understanding and effort, but was also wary that they could divert time and attention from each period's objectives. For example, when a SIQ was asked during the few minutes at the end of class, he engaged in an extended dialogue with three students about the question. This action was in line with his beliefs that SIQs can help him diagnose student understanding and that students who frequently ask them are intelligent and understand the lesson. However, when a student asked an SIQ during the time he had allotted for the lesson, Mr. Kelso deflected the question. This behavior was aligned with another set of beliefs, in which SIQs were seen as annoying and a disruption to the lesson. The difference in Mr. Kelso’s responses in the two situations is connected to the pressure that Mr. Kelso felt to cover the material the students will need for the next year’s class. If his students are not prepared, Mr. Kelso will have let down his students and the instructors in the science department who will be teaching the students in the future. This example shows that while a teacher’s decisions are influenced by his beliefs, these beliefs can be shaped by the environment in which they work, which in this case is the limited class time and the departmental value that good teachers “cover the book.”

These results from teacher literature align with the analysis of Chapter Four, which shows how context can affect instructor practice. This chapter describes the differences in context at two universities and argues that these differences help account for observed differences in buy-in to reform curriculum from TAs at the two universities. These contextual factors include some of the issues that Borko and Putnam mention, such as university policies and expectations of students and supervisors.

2.4.3 Teachers can improve their practice by improving their pedagogical content knowledge

While some education researchers have focused on the effects of insufficient content knowledge of preservice science teachers, this has not been a significant concern for those involved in TA training. There is anecdotal evidence that graduate students have conceptual difficulties with the introductory material that they teach (Roehrig, et al., 2003; Stetzer, 2010), but it is difficult to find research investigating how TAs' content knowledge (or lack of it) affects their teaching.[1]

An aspect of graduate student knowledge that likely to be lacking is pedagogical content knowledge. Schulman (1986) argued that the focus on pedagogical knowledge at that time was ignoring the importance of a different kind of knowledge, what he called pedagogical content knowledge (PCK). This category includes knowledge needed to teach a particular subject: the ideas and knowledge the students might bring to the classroom, common misconceptions or difficulties, and multiple presentations of a topic, including metaphors, rephrasings, and examples. This is the knowledge that TAs, who have previously participated in classes only as

[1] The University of Washington (UW) physics education group routinely asks physics graduate TAs to complete conceptual tests. The TA results are compared to undergraduate student and in-service teacher post-test results after instruction using the curricula developed at UW. It is not unusual for undergraduates or in-service teachers to meet or exceed the level of conceptual knowledge of TAs (McDermott, 2001; McDermott, et al., 2006). These results suggest there is potential for improvement in TA conceptual understanding.

students, may well be lacking, because understanding the various ways that students can make sense (or fail to make sense) of a particular subject goes beyond understanding how you made sense of the subject as a student. Research on teachers has demonstrated that helping teachers gain PCK is a difficult task (Lederman, Gess-Newsome, & Latz, 1994), even when the explicit focus of the PD is on that task (Fennema, et al., 1996; Franke, et al., 1998; Franke, et al., 2001; van Driel, Verloop, & de Vos, 1998).

Research on pedagogical content knowledge has not been used in isolation to explain teacher behavior, but rather is considered in conjunction with teachers' beliefs, goals, or content knowledge to account for their practice. It has also been used to explain improvements in teacher instruction. There are at least two ways that teachers' increased PCK can lead to improved science instruction: PCK helps teachers recognize student ideas more easily and it allows them to prepare instruction that anticipates common student difficulties.

A demonstration of how improved PCK can lead to better instruction is found in a study of an experienced math teacher teaching at a Midwestern urban middle school (J. Seymour & Lehrer, 2006). The teacher, Ms. Gold, is teaching a unit connecting algebraic reasoning to geometric ideas. The case study is built on video clips of lessons where Ms. Gold wants to her students to learn about slope using various representations, such as Cartesian graphs, equations of the line, and similar rectangles. She begins by asking students to use their similar rectangles (a group of rectangles whole sides have the same ratio) to write an equation for the steepness of the line, but the students do not understand the task. Following the suggestion of the participating researcher, she asks them how a graph and the corresponding equation "do" the same kind of multiplication. This prompts many students to explain their ideas. Eventually Ms. Gold assigns each student the task of writing a rule that will tell another student how to reproduce a line. In the initial task, Ms. Gold cannot make the students understand her question, but after a different question provides a place for student ideas, she tries to makes sense of the various ideas being presented. This allows her to become more familiar with the different ways students describe slope and she begins to align her word choice and use of representations with those of her students. When she teaches this lesson again the next year, she is better able to assess student difficulties and to tailor her assistance to respond to student thinking and context. This is due to her improved PCK relating to the particular topic of slope. She can now make sense of more student ideas and can employ an array of tasks and questions that have proved successful from the previous year. In addition she continues to adapt to the new ideas that she hears from her students. This case study shows how the teacher's ability to translate between her students' ideas and the target concepts improves as her PCK improves.

The analysis presented in this dissertation does not specifically address TAs' PCK. The results discussed in this section demonstrate that increased PCK can improve instructors' abilities to teach in a reformed manner, and this suggests that TA instructors should consider PD that improves TAs' PCK. At the University of Colorado, Boulder, undergraduate Learning Assistants (LAs) participate in a semester-long course to improve their PCK; the use of LAs in tutorial instruction has significantly increased student scores on the standardized Force and Motion Concept

Evaluation, even in comparison to reformed classes that did not use LAs (Otero, et al., 2006). However, increased PCK does not automatically lead to changes in instruction: Pellathy's work to improve physics TAs' use of representations in problem solving (discussed in Section 2.2.4) showed that after explicit instruction on relevant PCK, TAs showed increased knowledge about various problem-solving representations but this knowledge was rarely used during their teaching (Pellathy, 2009). It may be that increased TA PCK needs to be accompanied by changes in beliefs and attitudes about teaching and learning before sustained changes in classroom practice are observed.

2.4.4 Conclusion

The limited amount of research on STEM TAs has demonstrated that PD can lead to changes in their beliefs about teaching and learning and their understanding of what constitutes good teaching. PD programs can also increase TAs' pedagogical content knowledge and their confidence in their abilities. Research on how these changes in TAs beliefs, knowledge, and attitudes translate to changes in classroom practice is insufficient. When TAs' teaching is observed, their teaching is often categorized in simple ways; detailed observations by researchers like Speer (Speer, 2001) show how we can improve our understanding of how TAs' motivations underlie their behavior.

The more extensive research on teacher practice provides insight into how TA PD can be improved. While the similarity between teacher and TA influences cannot be unproblematically assumed, work showing the influence of teachers' beliefs, context, and PCK on their teaching practice lead us to expect similar influences on TAs.

This chapter has established the need for additional research on physics TA PD and TA practice. The next chapter describes the theoretical framework that underlies the research on TAs to be presented in Chapter Four through Six.

Chapter 3 A theoretical framework for explaining interactions and cognition

3.1 Introduction

The work in this dissertation is primarily concerned with generating explanations for TA practice in the classroom. The analysis is based on data from two sources: episodes of TA/student interactions and interviews of TAs discussing their teaching and their students. I want to be able to explain TAs' teaching decisions using both environmental factors and elements of their thinking. I use video of TAs and students in the classroom to both identify teaching practices and, in part, to explain those teaching practices. Thus, Section 3.1 discusses how I interpret what goes on when people interact with each other. I also explain TA practice with the interviews in which TAs discuss their teaching. Because I analyze TA thought, I use the next two sections to enunciate my assumptions about what grain size we should consider when analyzing thinking and how cognition is organized. Section 3.3 discusses whether I analyze thinking as it is occurring in an individual's mind or as individuals interact with their larger environment. Section 3.4 describes how I understand the nature of the "stuff" in people's minds (including ideas and beliefs). Lastly, because I use what the TAs talk about in their interviews to characterize their beliefs, Section 3.5 introduces my definition of the term 'beliefs' and discusses two characteristics beliefs sometimes have: context-dependence and stability.

To see the type of questions I address in this chapter, consider an excerpt of a teaching episode that is discussed in Chapter Five. In this episode, a group of four students has called a TA, Alan, over to the table to ask him a question about the problem they were working on.

S4: How does this look to you?
[Alan looks at S4's paper]
S1: It's like the opposite of the…
Alan: Well, yeah, that's what it ends up looking like. I mean, I'm not sure that you can always say that it will be the exact opposite of… Maybe this one, in this case it happens to be.
S3: Okay.
Alan: But, I mean, I'm guessing you guys sort of thought this one through and sort of figured out-
S3: Yeah.
S4: Yeah.
Alan: -why it would look like that.
S4: Yeah, definitely.

This episode proceeds so unproblematically that it is easy to gloss over how Alan and the students have established, with minimal effort, an agreement about what should be happening, namely that Alan should verify that the students' are doing the right thing. What assumptions underlie this shared understanding that the TA's job is to check answers? How do Alan and his students decide what they should be saying or doing in each moment? What verbal and nonverbal signals do they provide to each other to verify that they are understanding what is going on in the same way? In addition, if we say that Alan "thinks" he should be doing something, is this idea something we expect to be consistently influencing his teaching, or will it depend on the particular context?

To begin with, let us consider the first issue, which is how I explain what is happening when people interact.

3.2 Explaining interactions: Framing

3.2.1 The answer to "What is it that's going on here?" is how individuals figure out what to do next

As mentioned in the introduction, the central goal of my work is to understand TAs' teaching. In part this is done by examining episodes of instruction to determine what TAs think they are doing in the classroom and why they might think that behavior is suitable. Every time individuals (in these cases, a TA and students) have an interaction, each person must decide what activity he or she is engaged in, based on the environment and the conversation and body language of the other participants. This decision is usually unconscious and is constantly being revised as the interaction continues. In other words, a TA and his or her students are unconsciously working to answer the question, "What is it that's going on here?" (Goffman, 1974, p. 8).

Framing is the process of determining the answer to this question. The construct of framing, developed in anthropology and linguistics (Bateson, 1972; Goffman, 1974; MacLachlan & Reid, 1994; Tannen, 1993a) includes people's use of expectations of what actions are appropriate and what events might be expected in a particular situation. Framing also helps direct an individual's attention (Hammer, Elby, Scherr, & Redish, 2005b). An example of framing is the interpretation of a loud debate as either a friendly discussion or an argument. Similarly, a teacher may frame a physics problem as an opportunity for sense making or as an occasion for rote use of formulas.

To see how a person's framing affects his behavior, consider a father at his child's soccer game. He might frame his activity as rooting for a sports team or as time to nurture children. How he frames the soccer game will lead him to notice different things: if he is rooting for a sports team, he may pay attention to who is scoring points, whereas if he is nurturing his child, he may note who is having fun. This would also affect his behavior, leading to more partisan cheering in comparison to general encouragement. This example also demonstrates the role of context in framing, because a league championship might be framed as a competition, while an unscored scrimmage is more likely framed as an opportunity for fun. Contextual cues can also cause a change in frames, such as when a father rooting for the team suddenly focuses on his child's wellbeing if she is injured.

Because all the episodes I analyze involve students working collaboratively in the classroom while interacting with their TAs, there are two types of framing that are particular interest: epistemological framing and social framing. Epistemological framing refers to how teachers and students figure out which of their expectations about learning and teaching are relevant in the particular situation (Redish, 2003). In the introductory example, Alan's students seem to have expectations that they should agree on the answer they choose, and that one of the TA's jobs is to make sure they have the right answer. Social framing involves individuals forming an idea of what they should expect from each other during interactions. In the above example, students expect that they can call the TA over when they need help, and Alan probably expects that his students will listen to him when he is speaking. For individuals working together collaboratively, the social and epistemological aspects of framing interact. A TA who thinks it is important to build on student's ideas may frame a discussion as "understanding a student's idea of momentum"; the same discussion could also be framed as "checking a student's answer" if the TA was helping students prepare for an upcoming exam.

3.2.2 How individuals frame depends on the context and how other participants are framing the situation

Framing allows TA's behavior to be explained by both the immediate situational characteristics as well as the indirect influences from past experiences. How a person frames is influenced by the past, when previous interactions helped create her expectations about the current situation. The immediate situation influences her framing as all the participants interact using speech and nonverbal signals to form their shared understanding of the activity.

The episodes I consider in the analysis chapters demonstrate how TAs' framings are influenced by both internal expectations and external cues from the environment and other participants. In Chapter Four, I discuss how the TA Oscar's beliefs, focus of attention, and behaviors all interact, feeding back into each other to help him establish a stable epistemological frame. I assume that context will affect TAs' thinking and actions in the tutorial classroom. This assumption is supported by the analysis in this dissertation. The case study of Alan, discussed in Chapter Five, provides an example of how context helps shape his teaching decisions: in one episode he frames the interaction as checking an answer, whereas in another he sees his job as giving a hint. In Chapter Four, I also provide examples of how the social and environmental context affects how TAs frame their tutorial teaching.

A group's framing of an interaction becomes stable when the individual ways of framing reinforce each other. Because framing takes place continually, the behavior of others then becomes further information that individuals can use to check whether they are framing in the same way as the group. We see, when examining episodes of Alan's teaching in Chapter Six, that when Alan frames an interaction as "answering a question," his students provide cues that support his understanding that this is an appropriate activity. They expect help, and consider TA-led explanations appropriate in discussion sections. They listen attentively, ask questions to clarify what he is saying, and direct their attention to him; these actions all reinforce Alan's idea that answering their question is the right thing to be doing.

3.2.3 Framing in other disciplines

Frames, scripts, and schemata are related and overlapping terms in the fields of linguistics, artificial intelligence, cognitive psychology, social psychology, sociology, anthropology, and other disciplines.[2] My use of framing is most closely related to work done by Goffman (1974) and Tannen (1993a). Goffman, a sociologist, used frames to understand how experiences are organized. His frames are often generalizable to the human experience and he draws on examples from newspapers and literature to explain his frames. For example, he suggests categories of frames that include interpreting events as "stunts," which push the boundary of what a person expects but still is explainable. This contrasts with an "astounding complex," in which a natural event is not explainable with natural laws. Goffman's goal when using frames is different than mine, because he seeks to understand how people in general make sense of the events that happen to them, while I examine particular individuals. His work does not suggest particular frames that we would expect to see

[2] An overview and history of the uses of these related terms appears in Chapter One of Tannen's Framing in Discourse (1993a).

in classrooms, but he does provide explanations for how frames function that are directly applicable to understanding instructors and students in the classroom. For example, Goffman identifies "out of frame" activities as those that people know they should not directly attend to. An example would be one student asking another to borrow a pencil while the TA is talking to the group. The other students know in this case that they are supposed to continue paying attention to the TA rather then the side conversation. Similarly, Goffman's "flooding out" occurs when a frame is broken through intense laughter or the realization that participants have been framing the interaction in different ways. In the classroom, this might occur if one student cracks a joke in the middle of an intense argument; the resulting laughter might flood out the frame and change what the students are doing.

Some linguists use frames to analyze the particular actions of individuals (Hoyle, 1993; Tannen, 1993a; Tannen & Wallat, 1993). Tannen's work describes how expectations are formed, how researchers can see evidence of these expectations, and how these expectations influence participants' behavior. As Tannen explains it, people interpret their situations not in a sterile, rational way; instead their interpretations are influenced by their past experiences. As experiences accumulate, people organize them into typical event sequences (which Schank and Abelson call scripts (Schank, 1980)) that they can then draw on in new, but similar, situations[3] (Tannen, 1993a). As people engage in the situation, "structures of expectation make interpretation possible, but in the process they also reflect back on perceptions of the

[3] One frequently used example is the fast-food schema, in which a menu on the wall, plastic tables, and food served in disposable containers cuse a relatively stable set of expectations: that customers order and pay for their food before they sit down and that the food will be inexpensive (Redish, 2003; Schank, 1980).

world to justify that interpretation" (Tannen, 1993a, p. 21). Thus, expectations guide behavioral choices, but the results of these actions are then compared to the set of expectations originally used and the actions and expectations continually feed into each other.

The work presented in this dissertation is heavily influenced by Tannen's style of analysis, including types of evidence and how interactions influence framing. Among other evidence of frames (which I discuss in Chapters Four, Five, and Six), I use Tannen-identified linguistic markers such as omissions, hedges, and evaluative language. In Tannen and Wallat's analysis of a conversation between a girl, the doctor examining her, and the girl's mother, the doctor shifts frames quickly as she teases the child, answers the mother's questions, and narrates her results of the examination for a video camera recording being made for other doctors (Tannen & Wallat, 1993). In this case, the doctor frames her activities differently for each of the three audiences. As she interacts with the child to build rapport and examine her, and with the mother to discuss the child's health, interactions can shift or reinforce her framing. For example, the mother withholds her question while the doctor is reporting her findings to the camera, reinforcing the "reporting frame."

3.2.4 Explanatory trade-offs between direct local and indirect contextual factors

One of the tensions in describing behavior is how to account for the influence of both moment-by-moment interactions and the larger context in which individuals live and work. The tension is particularly salient to the analysis in Chapter Four, which discusses TA buy-in to reform instruction at two different universities. In that chapter, my use of framing is influenced by the work of Erikson (2004), who stresses that there is a tradeoff between scope and precision. When we consider how an individual's actions at a particular instant are affected by his moment-by-moment context, such as the particular students a TA is addressing or the particular problem they are solving, we can make quite specific arguments about these influences. At the same time, we are rarely able to trace how the larger context might be influencing particular decisions. In addition, this immediate explanatory power does not extend to other TAs or even the same TA in other circumstances.

When we step back to consider how that same TA's behavior is influenced by the larger environment, such as the attitudes of his coworkers or the type of class he is teaching, our explanations must necessarily become broader. That is, considering the larger context allows us to account for TA behavior by considering his past experiences and the large-scale situation in which he is working. These influences cannot be captured by videotape, and force us to make more general claims about their impact on the individual TA. The ability to make arguments about groups of TAs who share similar contexts helps compensate for the lack of detailed explanations.

3.2.5 Framing does not imply a particular cognitive perspective

In the previous section, I presented framing as a way of accounting for how people navigate their interactions with people and objects in the world. This framework allows for at least two players – the person (or group) who is framing, and the person (or people or objects) with whom the person (or group) is interacting.

What has not been made explicit so far in the discussion is whether it is most effective (for the analyses presented here) to consider the cognition that motivates people's behavior as residing in one individual, a group of people, or people and their environment as a system, and whether using the construct of framing requires me to choose one of these perspectives.

As I discuss in Section 3.3, there are different ways to think about where cognition takes place. The cognitivist perspective focuses on thinking as it happens in the mind of a single individual, while the socio-cultural perspective focuses on cognition as it occurs within individuals' interactions with each other and their environment. Framing is compatible with either of these perspectives; thus, the use of framing does not force the choice of either perspective. For example, a researcher using a cognitivist perspective and framing might focus on the expectations an individual brings to a particular situation and how this individual interprets signals from other participants to either verify or contradict her understanding of the situation. On the other hand, a researcher with a socio-cultural perspective might use framing to attend to how the participants mutually construct a shared understanding of the nature of their activity. In the following section, I argue that both of these perspectives are different ways of explaining the same phenomena. They do not provide fundamentally different explanations for what is taking place; instead, each perspective highlights different aspects of the situation, which allows different questions to be answered.

3.3 Thinking can take place both in the mind and in interactions

The cognitivist and socio-cultural perspectives both address the issue of what grain size we can consider when studying cognition. Both acknowledge the role of the individual and what happens in her head, and the role of the people and the environment with which she interacts. They differ in whether they emphasize the role of the individual or the role of the interactions.

When the physics education community discusses how theories can be understood along the socio-cultural to cognitive spectrum, these discussions are usually focused on learning. My work rarely addresses the question of how learning is occurring, for TAs or for students. However, explaining TA practice very much relies on understanding the cognitive processes that guide behavior in the classroom. Thus, the question I must answer here is which grain size will be more appropriate to my analyses.

3.3.1 Cognitivist perspective

The cognitivist perspective takes the individual and his thoughts as the appropriate unit of knowledge. Knowledge is a "structure of mental representations" (Greeno, 1997, p. 92); in other words, when a researcher using the cognitivist perspective says a person knows something, it means that that person has cognitive structures, such as concepts or beliefs, or demonstrates abilities like reasoning and problem solving that are seen to stem from these concepts (Cobb, 1994; Greeno, Collins, & Resnick, 1996).

This view holds that a person learns by actively constructing knowledge. A researcher using this perspective would focus on the cognitive components such as beliefs, goals, and knowledge that a person possess, and use these components to explain a person's actions (Greeno, et al., 1996). While the role of the world in which the person acts is acknowledged and valued, the primary focus is on an individual's mind.

To better see the assumptions and the ways attention is focused within this perspective, consider Speer's study (2001) of mathematics TAs that was discussed in the previous chapter. Speer gathered data on two TAs, Zachary and Karl, by videotaping their teaching and then discussing the TAs' beliefs and teaching practices as prompted by viewing the videotaped teaching with them. Speer sought to draw out fine-grained differences in the two TAs' behaviors and beliefs. This included constructing "belief profiles" of each individual's beliefs about students, teaching, mathematics, and how learning occurs. These belief profiles were a way to characterize differences in the two TAs.

This work largely springs from a cognitivist perspective. The attention is on the beliefs that are in each TA's head, and these beliefs are used to explain each TA's teaching behaviors. Because the behaviors that are discussed are taken from particular video episodes, the behaviors are embedded in particular contexts. While the context, including what the students say and what they have written on their worksheets, is considered and used to help explain the behavior, the primary focus is on how the TA's beliefs drive their behavior.

3.3.2 Socio-cultural perspective

The socio-cultural perspective takes as its unit of analysis the "individual-in-social-action" (Cobb, 1994, p. 13). That is, the mind of a person cannot be separated from the context in which the person is acting and knowledge is seen as something that is distributed across the people and the things with which they interact, in contrast to a cognitivist understanding that knowledge resides in someone's head. This perspective focuses on understanding the situation as a whole, rather than the individual actors. For example, Hutchins (1996) examines the navigation of a ship in a port, a complex task requiring many people to coordinate different pieces of information, which included taking bearings and locating the ship's position on a map. Individual's activities are considered, because the role of the bearing taker is different than that of the log keeper. But the unit of analysis is the navigation team and their tools as a whole. This larger unit allows us to better understand how the action of maneuvering the ship takes place, because the action itself depends on many people and their interactions with the objects around them.

From the socio-cultural point of view, learning occurs as people involve themselves in a community of practice (Cobb, 1994). Because knowledge is demonstrated through participation in a community, learning happens as people gain the ability to participate (Greeno, et al., 1996). In the case of a graduate TA, learning how to teach includes learning how to explain concepts to students and participating in discussions with colleagues (other TAs and professors) about how to help students learn.

Consider an example of a classroom study that was conducted from a socio-cultural perspective. Roth et al. (1999) examined how the arrangement of a classroom affected how sixth and seventh grade students participated in a science unit on simple machines. The data collected included video recordings of the activities, photographs of the position of objects in the room, observations, and interviews. The researchers investigated how particular artifacts, such as projectors and experimental equipment, affected student participation. For example, when class ideas were recorded on a transparency, it provided a way for all participants to see the ideas, but which ideas were recorded and how they were written down was mediated by the teacher. When students worked on projects in small groups, they were able to help each other more and they were all able to participate and manipulate materials. However, the activity also loosened the constraints on the content so that discussion was not always on scientifically productive content.

The socio-cultural perspective used in this study supports the researchers' focus on how the context allows for and encourages particular kinds of participation from the individuals. The students are not analyzed separately from their environment in which they are learning, which includes the instructor, the objects they are using to do their experiments, the layout of the classroom, and the types of activities in which they are engaged. The focus is on how the environmental aspects affected the activities of the group of students as a whole. In contrast, a cognitivist view might have focused on how individual students interacted with the environment, such as whether a student's actions were aligned with the context or how a student used or ignored objects during that class's activities.

3.3.3 Choosing a perspective of where thought occurs

On a spectrum spanning cognitive and socio-culturally oriented perspectives, the work presented here lies somewhere in the middle. Consider, for example, the analysis of TAs' buy-in to tutorials that is presented in Chapter Four. The data I use to measure TAs' buy-in comes from interview excerpts. These interviews were intended to elicit TAs' thoughts and beliefs about tutorials, and thus I consider the beliefs that they discuss there to be limited to the context of their teaching of tutorials in an introductory physics course. Although the context is seen as restricting the application of these beliefs (i.e. I do not necessarily assume that the TAs would profess the same beliefs about their own learning), the use of beliefs in that case means that I am focusing on individual TA's ideas. The analysis in Chapter Four also depends on data and analysis that align more with a socio-cultural perspective. A case study in that chapter shows how one TA's behavior is influenced by his beliefs and how his students' responses to that behavior interact in the moment to affect his practice. This pulls the focus of analysis away from what is exclusively in the TA's head to include how the immediate context, including students' responses, the topic being discussed, and terminology in the tutorial, interacts with the TAs' beliefs and knowledge to shape his teaching decisions. At the end of that chapter, I also use a grain size that is larger that what might be expected from either a cognitivist or socio-cultural perspective. This occurs when I describe the different elements of the "social and environmental context" at two institutions and how these elements might plausibly affect TA buy-in. That section acknowledges that beliefs and knowledge are not acquired in a vacuum. Instead, past experiences influence what beliefs a person holds, and the larger environment in which the TA works, including departmental norms, opinions of peers, the type of class they are teaching, influence which beliefs are actively influencing their practice.

This is only one example of the analysis that is presented, but it is representative of the perspective I use. The cognitive perspective gives us tools for understanding what is going on in a TA's mind (so far as that is possible) and how these cognitive elements influence decisions. The socio-cultural perspective provides a way to see how the rest of the world reacts to and interacts with a TA's decision, which then affects the next decision. The choice of whether to focus on the mind of an individual or the individual's interactions with the world depends on what question is being investigated.

The effect of a choosing (whether this choice is conscious or not) a more socio-cultural- or more cognitively-oriented perspective affects not only the conclusions I might draw but also what questions I might ask. Otero cites a particularly illustrative case, in which biologists studying sea sponges only recently found that these stationary animals orient themselves so that sea currents transport food to them. This had not previously been noted because biologists had been studying the sponge as a unit, rather than the sponge-water system ((Clark, 1998) as cited from (Otero, 2003)). When they considered the interaction of the sponge and its environment, they were better able to understand how the sponge functions.

In this section I have discussed the need to consider what is happening in a TA's mind as well as the environment in which the TAs teach. When we consider what goes on inside the mind, however, we must consider how ideas are structured in the mind, because this has implications for how we expect to help people learn or change their ideas. The next section addresses this question.

3.4 Elements of cognition: Resources

3.4.1 A resource framework considers whether ideas are appropriate to the given context, rather than right or wrong

In this work I explain cognition using a resource-based framework, in which learners (whether they are students or beginning teachers) have ideas that are activated in different situations. People use these activated resources to construct knowledge and guide their behavior. These ideas are not categorically wrong or right, but rather are appropriate or inappropriate for the particular situation (Hammer, et al., 2005b). Such a framework provides an explanation for how novices can become experts: they begin to use resources from other contexts, adding new ones, and build up a more coherent structure of ideas (Smith III, diSessa, & Roschelle, 1993) Smith et al. characterized such a framework as one that "emphasizes knowledge refinement and reorganization, rather than replacement, as primary metaphors for learning (1993, p. 116)."

3.4.1.1 People have knowledge which is varied, context-dependent, and sometimes contradictory

The idea that people construct knowledge in the moment using smaller knowledge elements contrasts with an idea that views people's thinking as arising from more permanent, stable, and coherent knowledge structures. The latter framework is often called a misconceptions framework, because it characterizes students as having stable, incorrect ideas called misconceptions. Misconceptions are ideas that originate from previous learning, and they are usually identified because they are widespread (i.e. seen in many students), stable, and resistant to change.

Research that deals with misconceptions frequently has two goals: to identify misconceptions and to replace them with correct knowledge. In order to learn correct ideas, students' misconceptions must be elicited, then effective instruction leads them to confront the misconception and discover why it is wrong. After that, students can learn a more expert idea (Smith III, et al., 1993).

In contrast, a resource framework maintains that misconceptions are not always stable knowledge structures but rather concepts that are applied in the wrong context (Smith III, et al., 1993). The concepts are robust because they have the ability to explain aspects of the world when they are activated in some contexts, but are categorized as wrong when activated in others. Smith et al. argue that the misconceptions framework conflicts with how constructivism theorizes that learning takes place. If we categorize the majority of a students' knowledge as either correct or part of a misconception, it is difficult to account for what pieces students have that they could productively use to construct the correct knowledge, because the misconception model does not provide these pieces. Smith et al. also argue that a premise inherent in much misconception research, that instruction should confront misconceptions, is flawed. They argue that confrontation in instruction can convey to students that attempts to build understanding are ineffective.

These arguments have primarily been made in the context of student ideas, but they apply equally well to the thinking of instructors. My analysis does not rely on the details of what the resource framework has to say about how concepts are organized or the size or permanence of resources. The primary idea that I draw from this framework is that people's minds contain smaller cognitive elements upon which they can draw. Thus, analyzing TAs' thinking from a resources perspective rather than a misconceptions perspective allows us to consider professional development for TAs that can identify and build upon some of the cognitive elements that they have available.

3.4.2 The resource framework is consistent with respect for instructors' naïve ideas

3.4.2.1 We should respect novice teachers' ideas as we respect novice students' ideas

People do what they do partly because it has worked for them in the past. Teachers may teach in a traditional manner because it is the way that they have experienced instruction, and, in the case of physics graduate students, it is a system in which most of them have excelled. Because these behaviors and decisions have served TAs well in the past, it is unreasonable to expect them to simply discard them when TA instructors present alternative teaching methods.

I take a theoretical position of respecting naïve ideas. The physics education community has done so regarding people's physics ideas, with the benefit that we can help students identify ideas that can be the basis for effective constructivist instruction (Hammer & Elby, 2003) and where they will need to reconcile these ideas with formal physics concepts. The same theoretical framework applies when the "students" are novice teachers; now the naïve ideas can be a basis for effective professional development.

The idea of respecting novice TAs has two components. The first is treating TAs with courtesy, which includes considering TAs to be partners in the enterprise of educating undergraduate students. The research that is presented here supports the finding that failing to treat TAs in this way is one of the environmental components that leads to TAs' dissatisfaction with the curriculum they are teaching (Chapter Four). In addition, I argue that treating TAs as partners in education rather than as novice instructors to be continually corrected is simply the decent thing to do. The second part of treating TAs with respect involves looking for productive seeds within their existing beliefs. This second component is discussed in greater detail in the following subsection (3.5.2).

3.4.2.2 Part of respecting TAs' beliefs involves identifying productive seeds

The physics education research community uses students' ideas as a foundation for assisting students construct their own knowledge. We have learned that it is ineffective to ignore the ideas that novice students bring into the classroom. Similarly, we cannot assume that TAs will easily abandon the beliefs and practices they already use in their teaching. TA instructors can help TAs learn to teach more effectively by identifying beliefs and practices the TAs already have that they could draw upon. These resources include those that TAs already use in other contexts. For example, they have discussions with colleagues in which the answer is not known by one of the participants, and they can use this experience to encourage similar conversations among their students. Another productive resource would be conversations in which they try to understand an idea without evaluating it. Thus, a significant motivation for studying TAs' classroom practice is to better understand how TA instructors can foster situations where TAs can discuss their ideas about teaching and learning. The TA instructors can then create professional development programs that could build on the productive seeds they find in TAs' beliefs and values.

In this chapter, I have already repeatedly referred to TAs' beliefs. I would now like to more carefully define the term 'beliefs' and discuss two characteristics of beliefs may have, their stability and their dependence on context.

3.5 I use 'beliefs' to refer to TAs' declarative knowledge about teaching and learning

This work depends on using TAs' beliefs to explain their classroom behavior. The idea of beliefs has been defined in many ways, and I am using the term in quite a general sense, to describe the declarative knowledge that TAs have about teaching and learning. Other researchers have carefully defined how beliefs are different than knowledge, goals, and values (Pajares, 1992), but these distinctions are not critical to the argument that I am making. My use of the term *beliefs* does differ from how the term is often used in the established beliefs literature. Much of the research that uses beliefs to explain teachers' practice does not explicitly consider beliefs to be context-dependent; instead, they are seen as broad constructs that are relatively stable across varying contexts (Pajares, 1992). In this analysis, I begin with the assumption that the context TAs are in can influence the beliefs they draw upon.

3.5.1 Beliefs can be stable

One characteristic of the beliefs that I discuss in this work is that they are often stable. When I describe a TA's beliefs as *stable*, I mean that the ideas that TAs express in their reflections about their teaching are generally consistent with the teaching practices that we observe. I am not implying that these beliefs are consistent across all contexts and I am not taking a position on whether beliefs always exist in the mind.

Much of the data presented here shows TAs whose practice is consistent with the reflections they offer about that practice, which would seem to support a view of their beliefs that is more globally consistent across contexts than the perspective I have chosen. However, I argue that the narrow context in which beliefs are invoked is the reason TAs' practice and beliefs appear so consistent. The episodes of TAs' teaching that I analyze are all from tutorial classrooms, where these TAs are teaching introductory physics to junior and senior life science majors using tutorials. The reflective interviews attempted to elicit TAs' ideas about teaching and learning within this particular context. For example, the TAs were asked, "What do you see as the advantages and disadvantages of tutorial-style teaching for you and for your students?" The TAs' responses often included examples from their classroom or reactions from their students. Thus, it seems likely that the beliefs I attribute to the TAs are connected to this particular situation. The analysis I present here does not address the question of whether the stability of these beliefs would extend to other teaching or learning contexts.

3.5.2 Beliefs can be context-dependent

Part of my theoretical assumptions about beliefs are that they are context-dependent. The context can affect an individual's belief by influencing what beliefs are activated, as well as which of those beliefs the individual consciously decides are relevant to the situation. Consider the two episodes of Alan's teaching that I discuss in Chapter Five. Multiple behaviors could be supported by his beliefs, which include (1) the belief that students generally find conceptual physics questions easy but quantitative problems difficult and (2) the belief that teachers should usually be generous in attributing understanding. Alan's behavior is different in each episode, although in each case he is attending to relatively superficial evidence that students understand. His behavior differs because different contexts make certain beliefs more salient. In one case, the students have produced a correct qualitative answer, and Alan quickly validates their answer, supported by his belief that conceptual questions are straightforward. In the second case, the students are struggling with a formal physics question, and rather than leading them to the answer, he prompts them to think about one particular concept and indicates that they will have to do more thinking. The context of the second situation brings to the forefront his belief that formal, quantitative problems are difficult. His belief about the importance of giving students the "benefit of the doubt" means that he accepts their affirmation that they understand his hint but the particular context means that he is less likely to attribute as much understanding as in the previous case.

In this case, the effect of the each context is to "foreground" certain beliefs that Alan has. In all of the TAs that I discuss in this work, I do not observe that different situations in the tutorial classroom prompt conflicting beliefs in an individual TA. Instead, the context causes certain beliefs to become more salient at a particular moment.

The findings of this research support the idea that TAs beliefs and practice in tutorials are consistent. Thus, the idea that the TAs' beliefs are stable is an empirical result rather than a theoretical assumption. My initial expectations that individuals' beliefs are often influenced by context is what allowed me to see this result, rather than just assuming it.

3.5.3 Beliefs support (but do not determine) framing

I have discussed how beliefs and framing can both be used to explain people's behavior, but this then leads to the question of how the beliefs and framing are related. The relationship between beliefs and framing is one in which each component influences, but does not determine, the other. Thus, stable beliefs play a supporting role in framing. In example of a soccer dad discussed in the framing section, a man who believed in the need to develop toughness in a competitive world would more likely frame a soccer game as a partisan event than a man who believed that strong children are products of unconditional love. Beliefs can only influence framing, though: they cannot determine it, because that would exclude the effect of context, such as the other participants' responses. We would expect that how people regularly frame their activities could, over time, also influence their beliefs. In this analysis, however, I present minimal longitudinal data that could address this question. Therefore, my primary focus is on the effect of beliefs on framing.

How a TA frames her teaching is influenced both by her negotiations with students about what kind of activity they are all engaged in and by the stable beliefs that the TA has about teaching and learning. The TA may be guided by her beliefs about what would be appropriate in this situation, but the students' responses then either support or undermine the TAs actions, so that together they construct a shared framing of the activity. (This is not to say that participants always have the same framing: mismatched framing is common, and can lead to humor or conflict depending on whether the participants recognize that they are framing in different ways (Goffman, 1974).)

It is not unusual to find TAs that express apparently contradictory beliefs about teaching. This contradiction, however, can be explained by the role of context. People can hold contradictory beliefs that are nonetheless quite stable in particular contexts. For example, most people think lying is wrong, but complimenting someone's new hairstyle, regardless of its aesthetic appeal to you, is generally considered acceptable. Similarly, a TA could express his belief that tutorials are too easy for students, and yet also think that students cannot do them. Thus, when I claim that a TA's framing is supported by stable beliefs, I assume that he has other stable beliefs, which in a different context could have led to a different framing. For example, Chapter Four discusses the plausible relationship between TAs' buy-in and their social and environmental context; this analysis leads to the conclusions that changing the context in which TAs work would change their buy-in.

3.6 Conclusion

In this chapter, I have not attempted to lay out an argument for which theoretical framework is optimal for answering my research questions. This is because each of the upcoming analysis chapters asks a different kind of question, and there is not a single theoretical framework that spans them all. Each analysis chapter therefore includes a specific framework, which emphasizes different components of the perspectives I have discussed in this chapter.

I have attempted to present a description of the various perspectives and how they have been used. Framing provides a way to analyze an individual’s actions and account for them by understanding his expectations and the expectations of those interacting with him. A cognitivist framework places the focus of understanding thinking in a person’s mind, while a socio-cultural framework answers the same question by looking at the interaction of a person and their environment. A resources-based framework assesses resources based on their appropriateness rather than correctness, which influences my analysis of how we can help TAs learn to be better instructors. Together, these perspectives provide us with tools to better account for TAs’ classroom practice.

Chapter 4 Accounting for tutorial TAs' buy-in to reform instruction[4]

4.1 Introduction

Experienced tutorial instructors and developers are well aware that successful implementation of tutorials includes establishing norms for learning in the tutorial classroom. These norms include an emphasis on conceptual understanding (and a concurrent de-emphasis of algorithmic application of formulas); an expectation that this understanding is best achieved through explaining one's own thinking, listening and responding to others' ideas, and constructing arguments; and an acceptance of instructors as facilitators of this process rather than sources of correct answers. The establishment of these norms is "among the most critical and subtle features of implementing these reforms" (Finkelstein & Pollock, 2005). From the students' point of view, the teaching assistants (TAs) who lead each tutorial section are important arbiters of these norms and expectations. The development of these norms by the TAs is thus a critical task of tutorial implementation. TAs who "buy into" tutorials are more likely to convey their respect for the material and the tutorial process to the students, as well as learning more themselves. This development is nontrivial: although TAs may be presumed to be more sophisticated learners than their students, they are in some cases more thoroughly embedded in traditional teaching practices.

We are conducting a project whose long-term goal is to design an effective professional development program for physics graduate students who are teaching

---

[4] This chapter was previously published in Goertzen, R.M., Scherr, R.E., & Elby, A. (2009). Accounting for Tutorial Teaching Assistants' Buy-in to Reform Instruction. Physical Review Special Topics - Physics Education Research, 5, 020109.

tutorials. As we initially imagined it, such a professional development program would include activities and experiences to help the participants appreciate the power of tutorial instruction. We now suspect that typical professional development activities provided to TAs, such as completing the tutorial as if they were students and viewing pre/posttest and Force Concept Inventory results, are not likely to accomplish this goal on their own. Our observations suggest that the social and environmental context of the tutorials – including classroom, departmental, and institutional levels of implementation and support – strongly affects whether TAs buy into tutorials, and probably outweighs the influence of any particular activity or experience that we might prepare for them. We have chosen the term "social and environmental context" to emphasize two characteristics of the context: (i) the attributes affecting the particular situation come from both people and the environment and (ii) these characteristics are structural and have some permanence. We use the term "buy-in" to refer to the alignment of the TA's stated set of beliefs about how physics should be taught compared to the beliefs of the curriculum developers. Based on observations of tutorial implementations at the University of Maryland (UM) and University of Colorado – Boulder (CU), we argue that the social and environmental context at CU is more supportive of tutorials and tutorial instructors than the UM context. As a result, the TAs at CU buy in to tutorials more than the TAs at UM, which leads to specific, identifiable consequences in the classroom.

In what follows, we first provide a detailed example of one way the lack of buy-in from a TA named Oscar undermines the effectiveness of tutorials. Next, we use the framework laid out by researchers at CU (Finkelstein & Pollock, 2005; Pollock & Finkelstein, 2008) to consider how different levels of social and environmental context may affect the worth that TAs place on tutorials. Our observations highlight the need for further research on how professional development activities can support tutorial TAs in valuing reform instruction.

4.2 Research on TA instruction and teacher beliefs

4.2.1 Research on science TAs is limited and characterizes TAs beliefs and teaching styles in general terms

The physics education community has now produced many research based undergraduate curricula that help students construct their own physics knowledge (Crouch & Mazur, 2001; Heller & Hollabaugh, 1992; McDermott & Shaffer, 2002; Sokoloff & Thornton, 2004). The developers of these curricula have carefully studied how material should be presented and how students should best interact with it. Much less published research, by contrast, has focused on the TAs who, at many institutions, lead the discussion/ recitation sections in which research-based curricula are implemented. For example, a classic pair of articles describing the development of two particularly well-studied tutorials (McDermott & Shaffer, 1992; Shaffer & McDermott, 1992), describes the instructional environment in two paragraphs. The role of the instructors (who typically include TAs) is addressed as follows: "The instructors do not lecture but circulate throughout the room while the students work through experiments and exercises. A high instructor-to-student ratio allows the staff to engage students in dialogues that permit in-depth questioning" (McDermott & Shaffer, 1992).

Much of the limited literature on science TAs has characterized TAs with only the broadest of descriptions. Research that presents detailed descriptions of the development and implementation of professional development programs (Ishikawa, et al., 2000; Lawrenz, et al., 1992; Luft, Kurdziel, Roehrig, & Turner, 2004; McGivney-Burelle, et al., 2001; Price & Finkelstein, 2006) has often assessed the effect of TA participation in such programs by surveys or written assessments (McGivney-Burelle, et al., 2001; Price & Finkelstein, 2006) or with limited observations and/or interviews (Ishikawa, et al., 2000; Luft, et al., 2004). Case studies afford more nuanced descriptions of individual TAs, but the cases rarely include detailed descriptions of classroom interactions to allow a fine-grained analysis of individual actions (Belnap, 2005; Volkmann & Zgagacz, 2004).

4.2.2 Research on teachers' beliefs has demonstrated their effect on implementation of reform curriculum

While the literature on science TAs is very limited, the large body of research on teachers and their beliefs is a useful place to begin identifying influences on teachers' practice in the classroom. Numerous studies have shown that instructors' beliefs about their abilities as teachers, about how their students learn, and about whether they are in a supportive environment affect how reform curricula and methods are used. Case studies of math and science teachers provide examples of teachers who modified provided reform curricula to better fit their beliefs about how their students best learn (Cronin-Jones, 1991; Peterson, 1990; Wiemers, 1990; Wilson, 1990). Similar modifications were made by teachers on the basis of their beliefs about their own abilities and the support (or lack thereof) from their school environment (Haney, et al., 2002). Likewise, instructors' beliefs about the nature and purpose of formative assessment were seen to influence how it was used in the classroom (VK Otero, 2006). (For a fuller description of teacher beliefs and their influence on teaching, see Speer (2008) and Borko and Putnam (1996)).

4.2.3 Research has shown that reformed teaching correlates with student learning

The ultimate goal of TA professional development is increased student learning. Research has demonstrated that reformed teaching, as measured by the Reformed Teaching Observation Protocol (RTOP), correlates significantly with improved performance on the Lawson Test of Scientific Reasoning (Lawson, et al., 2002; Sawada, et al., 2002). Other studies have found that student gains are positively correlated with instructor participation in professional development designed to encourage a particular kind of "constructivist" teaching (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Ezrailson, 2004) and with instructor use of constructivist teaching (Schroeder, Scott, Tolson, Huang, & Lee, 2007). An extensive literature review by Close (2008) found that reformed teaching is the only teacher characteristic that is reliably correlated with student learning; studies of other positive teacher characteristics, such as more sophisticated nature of science beliefs or more years of schooling, have had mixed or inconclusive results.

4.3 Theoretical Framework

4.3.1 Epistemological Framing

Framing is a construct developed in anthropology and linguistics to describe how an individual or group forms a sense of "What is it that's going on here?"

(Bateson, 1972; Goffman, 1974; MacLachlan & Reid, 1994; Tannen, 1993b). To frame an event, utterance, or situation in a particular way is to interpret it based on previous experience: to bring to bear a structure of expectations about a situation regarding what could happen, what portions of the information available to the senses require attention, and what might be appropriate action. For example, monkeys engaged in biting each other are skilled at quickly and tacitly "deciding" whether the biting is aggression or play. An employee may frame a gift from her supervisor as kind attention or as unwelcome charity. A teacher may frame a physics problem as an opportunity for sense making or as an occasion for rote use of formulas. In school settings, epistemological framing is of particular importance: students and teachers form a sense of what is taking place with respect to knowledge, including, for example, what portions of information and experience are relevant for completing assignments. Other aspects of framing are important as well, including social framing, in which teachers and students form a sense of what to expect of each other and of themselves during interactions. For individuals working together collaboratively, the social and epistemological aspects of framing interact.

A frame becomes stable when the activated network of cognitive resources (elements of thought) are reinforced by each other and/or by social and material cues. We argue at the end of Section 4.6 that some of Oscar's behaviors as a tutorial TA reflect an epistemological frame whose stability arises from feedback loops among the underlying "beliefs," attentional focus, and patterns of action. This explanation differs from an account wherein behavioral patterns result from the global robustness of the teacher's epistemological (and other) beliefs (Brickhouse, 1990; Cronin-Jones, 1991; Haney, et al., 2002). By our account, we also expect — and in fact, observe — a fair degree of context dependence within a given TA's cognition and classroom behaviors, at various grain sizes. Some aspects of Oscar's teaching, not discussed in the paper, suggest this kind of variability. More importantly for us, in Section 4.8, we argue that specific social and material cues — specific components of the social and environmental context — affect how TAs frame their tutorial teaching.

In this way, framing is a useful construct for bringing both local action and more indirect contextual influences into explanations of TAs' behaviors. To the extent that framing is an interpretation based on previous experience, it is informed by an individual's broad history and experience with related events and systems. In the moment, though, participants mutually construct their sense of shared activity by means of verbal and nonverbal interactions, including linguistic signals, prosodic features, and body language (Bateson, 1972). Participants' understanding of the nature of the activity in which they are engaged — i.e. their framing of the activity — guides their selective attention, provides cognitive structure for interpreting events, and manifests itself in their observable behavior (Hammer, Elby, Scherr, & Redish, 2005a).

4.3.2 Explanatory trade-offs between direct local and indirect contextual factors

Our use of framing is informed by Erickson (2004), who emphasizes a trade-off between scope and specificity in explanation of behavior. Empirical study of specific interaction has crucial advantages: rich data, depth of analysis, and the hope of accounting for moment-to-moment actions, as we attempt in Section 4.6. This depth and explanatory power, however, comes at the expense of scope. In order to study how TA behavior unfolds in real classroom situations, we must choose a particular TA in a particular classroom at a particular time, interacting with a particular set of students. Studying specific episodes does not allow us to predict how other TAs would behave in similar situations, or even how our focal TA would behave in different situations.

By contrast, in our Section 4.8 analysis of social and environmental influences on TAs' behavior, we emphasize scope while sacrificing specificity. We can argue that social forces affect TAs in particular ways, but heeding Erickson, we do not try to show how that large-scale effect plays out in local situations. For example, the "upstream" influences that shaped a TA's behavior – what may have taken place in his history to cause him to behave as he does in the present – are not visible on videotape of his classroom behavior. Neither are the pressures he may be feeling from entities outside the classroom.

4.4 Instructional Contexts

4.4.1 University of Maryland

4.4.1.1 Course description

The teaching assistants (TAs) described in this study taught tutorials which took place as part of a two-semester algebra-based introductory physics course at the University of Maryland, with approximately 160 students in each lecture section, most of whom are junior and senior health and life science majors. The students, over half of whom are female, reflected the wide ethnic diversity of the University of

Maryland. Lectures are held two or three times a week in a large lecture hall and approximately 100-200 students comprise a lecture section.

The course was reformed as part of a project titled Learning How to Learn Science: Physics for Bioscience Majors, carried out at the University of Maryland from 2000-2005. The project adopted reforms that were well documented to produce conceptual gains and adapted them to try to create a coherent package that also produced epistemological and metacognitive gains (Redish & Hammer, 2009). However, most of lecture sections (four out of the six) were not taught by PER (Physics Educated Research) -affiliated professors and thus the lecture instruction was largely traditional in those sections.

As part of the course reform, the traditional teaching-assistant-led recitation was replaced with worksheet-based group-learning activities ("tutorials") based on the model developed at the University of Washington (McDermott & Shaffer, 2002; McDermott, Shaffer, & Somers, 1994). In the tutorial sessions, students worked in small groups on worksheets that led them to make predictions and compare various lines of reasoning in order to build an understanding of basic concepts. TAs served as facilitators rather than as lecturers. Each class section consisted of six groups of four students each, supervised by two TAs. The tutorials were constructed to emphasize the reconciliation of everyday, intuitive thinking and experience with formal scientific thinking, as well as to encourage explicit epistemological discussions about the learning process (Elby, 2001; Elby, et al.).

4.4.1.2 Teaching Assistants

The majority of the UM tutorial TAs who participated in this study are first or second year graduate students assigned to work as teaching assistants to support themselves before joining a research group. Most are chosen as a matter of convenience, not because they or the lecturer requested the assignment. A few are upper level graduate students who had unfunded research positions. Most are in their early twenties. During the two semesters of this study, the only women assigned to teach tutorials were physics education graduate students, who were excluded from the study. Thus, all the TAs in the study are male. They live in a suburban metropolitan area and attend a competitive research university with a large undergraduate and graduate physics program. Although almost half of the TAs who participated in the study are not native speakers of English, all but one communicate easily in English. Most of the TAs had entered graduate school immediately after their undergraduate studies, and only one (who had taught high school) had experience teaching beyond tutoring or leading discussion sections.

4.4.1.3 Tutorial preparation sessions

The UM tutorial preparation sessions are weekly, one-hour meetings in which TAs prepare to teach the next week's tutorial. The TAs sit in groups of two to four at tables in the tutorial room. The session usually begins with a discussion of content problems the students had during the previous week or with a conversation about classroom management issues, which lasts from ten to thirty minutes. The TAs spend the remaining time working on the upcoming tutorial. The tutorial supervisor circulates, modeling appropriate instruction techniques and highlighting anticipated student difficulties.

4.4.2 University of Colorado

4.4.2.1 Course description

The teaching assistants who participated in this study taught tutorials associated with a two-semester calculus-based introductory course at the University of Colorado, Boulder. The students in these courses are mainly engineers and natural science majors. More than half of the students are freshman, and 75% are male. Lectures are held three times a week in a large lecture hall and approximately 200-300 students comprise a lecture section. This course was reformed during a large-scale project from 2003 to 2007. These reforms included increased use of research-based methods such as concept tests in lecture and small-group activities. They also focused on sustaining these reforms across multiple lecture instructors, including those not associated with the physics education research group. The result has been increased conceptual gains (Finkelstein & Pollock, 2005; Pollock & Finkelstein, 2008).

A significant part of this reform was the implementation of tutorials, the worksheet-based group activities developed by the University of Washington (McDermott & Shaffer, 2002; McDermott, et al., 1994), which replaced traditional discussion sections. Students work in small groups to complete ungraded worksheets that lead them to build their own understanding of basic physics concepts using discussion and prediction. The students complete a pretest to elicit preconceptions before their tutorial section and are assigned tutorial homework after the section. At

CU, each tutorial section is taught by one TA, a graduate physics student, and one learning assistant (LA), an undergraduate student who attends a semester-long course on theories of learning and teaching methods. Each tutorial section has six or seven groups of four students each.

4.4.2.2 Teaching Assistants

The CU TAs who participated in this study were all first year graduate students who had taught tutorials in the fall (either in mechanics or electromagnetism) and were assigned to teach the tutorials for the introductory mechanics course during their second semester. Some had previously tutored, but none had taught in a classroom before the current year. The TAs who participated were all male and in their early twenties. One was a non-native speaker of English but communicated easily in English. The TAs live in a suburban area and attend a competitive research university with large graduate and undergraduate physics programs.

4.4.2.3 Tutorial preparation sessions

The CU tutorial preparation session takes place two days before the tutorial are taught and is attended by both TAs and LAs. The TAs are expected to arrive fifteen minutes earlier than the LAs, so that they can discuss the grading of the upcoming tutorial homework with the tutorial supervisor. After that, the TAs and LAs review a tutorial pretest that the students have completed. The remaining time, between thirty and forty minutes, is spent working through the upcoming tutorial. The tutorial supervisor circulates, sometimes discussing administrative issues and sometimes discussing the content of the tutorial. Unlike the situation at UM, the lecturer associated with the course often attends portions of the preparation sessions, modeling instruction techniques and answering questions.

4.5 Data collection and selection of episodes

4.5.1 Data Collection at the University of Maryland

4.5.1.1 Classroom video

At the University of Maryland, tutorials are held in a single room with six tables at which students work collaboratively in groups of four. Students typically do not move their seats during the class session, or even from week to week. We try to keep the recording of the tutorial activities subordinate to normal classroom practices, so two small Hi-8 or mini-DV video cameras on tripods are positioned on the periphery of the room, each focused on a single table. The cameras do not move. Microphones are embedded in cages on the tables that are being recorded. A researcher turns on the cameras at the start of the tutorial session, but the cameras are otherwise unattended. Our intention is to make the video recording as unobtrusive as possible, even at the expense of visual or sound quality.

4.5.1.2 Interviews

At the beginning and end of the first semester, TAs were interviewed by a PER researcher who was not associated with the TA training at UM. The interviews were either audiotaped or videotaped and lasted approximately an hour. A list of approximately ten open-ended questions was used as the starting point for the interview, which included questions about the TA's past teaching experience, advantages and disadvantages of tutorials compared to traditional discussion sections, and suggestions about how to make tutorials better. (Appendix 2 lists all the questions.) If TAs wished to discuss other topics relating to tutorials or the course we pursued those conversations first. In general, all the topics in the protocol were covered during the interview, either in response to the interviewer's questions or during discussions of issues raised by the TA. In our coding of TA buy-in, we used all portions of the interviews in which TAs discussed their opinions of tutorials. Discussions of the TAs' teaching histories, their comments about the lecture or labs, or their evaluations of how the students viewed tutorials were not included. However, these comments were included in our case study of Oscar.

The purpose of interviewing TAs at the beginning and end of the first semester was to have the opportunity to observe changes in their values. We observed, however, that some TAs' values changed a little and some showed no change (as detailed in Appendix 1). For this reason, we combined the data from the initial and final interviews. The observation that UM TAs' values did not change during their first semester of teaching challenges the model implicit in UM's TA preparation program, because we expected that the TAs' classroom experiences would be a primary influence on their beliefs. That is, it was hoped that as TAs participate in reform instruction, they would begin to value it (Lave & Wenger, 1991). Our data, in contrast, is more consistent with an account in which a given context (such as a tutorial classroom) evokes beliefs and actions that are stable and not easily modified.

4.5.2 Data Collection at the University of Colorado

4.5.2.1 Classroom video

The CU tutorials are conducted in an enormous room that contains areas for laboratories, homework assistance, discussion sections, and three subdivided bays for the tutorials. The tutorials for each course are all held on the same day of the week, so generally there are two or three occurring simultaneously. Each bay has seven or eight tables at which groups of four students work collaboratively. Like the taping at UM, the CU taping was arranged to minimize disruption to the students. Two tables were taped in each participating section by a mini-DV camera that was placed at least twelve feet away. There were small microphones taped to the middle of the table. Because tutorials occurred in different rooms, the microphones had to be taped down and cameras turned on in the few minutes before each class. The researcher made an effort to do this when only a few students were in the classroom, to avoid disturbing students and to make the recording as unobtrusive as possible. In most cases, the same tables were taped each week, but occasionally a different table was taped because it was more convenient.

4.5.2.2 Interviews

Because data collection at CU took place for only one month towards the end of the semester-long course, the TAs participated in one interview (in contrast to two interviews for UM TAs). The interviews were videotaped and took about an hour. The protocol for the CU TAs was the same as that used for the UM TAs.

4.5.3 Selection of TAs

At UM, 17 graduate students over two semesters agreed to be taped during their tutorial teaching. At CU, 4 graduate students and 2 undergraduate student TAs (who were participants in CU's Learning Assistant program) agreed to be taped while teaching. A total of 15 UM TAs, 4 CU TAs, and 2 CU LAs agreed to additional participation in the project, which included the completion of two interviews and one survey. They received a small stipend for this additional participation. We did not study TAs who were affiliated with either PER group, although some TAs chose to work with the PER group as research assistants after their participation in this project was completed.

As part of our larger project we chose a smaller subset of TAs to study in more detail. These TAs were purposefully chosen because they seemed articulate about their teaching or their students in preparation meetings or in their interviews. We excluded LAs at CU, because we viewed their experience as undergraduates with additional training as sufficiently different than the graduate TA population that was the focus of this study. We watched multiple clips of each TA interacting with students on video, seeking to describe and generate plausible explanations for the TA's action.

4.5.4 Selection of video episodes

During the two years we collected data, we videotaped 19 sections of introductory courses at UM, covering the entire semester of the introductory course. This resulted in approximately 340 hours of video. At CU, 18 sections were taped during one month of observations, which produced approximately 70 hours of video.

The two episodes that are described in detail in this paper were chosen while we were viewing numerous clips from a single TA, a process that we have repeatedly used to more deeply understand the classroom practice of individual TAs. These clips were chosen because they clearly illustrated the ways in which a TA's beliefs about tutorials influenced his use of them.

4.6 An example of TA buy-in and its effect on classroom interactions

Effective tutorial teaching requires TAs to support a variety of pedagogical ideas. For example, instructors need to maintain an environment in which students work in groups and TAs do not give students solutions. TAs must also value conceptual understanding and should encourage students to construct their own knowledge. In practice, we would expect that different TAs would buy into these different components of tutorial instruction to varying degrees. Thus their valuation of tutorials would not be along a simple continuum, but would require a more complex characterization.

In this section, we present a case study of a TA who buys into some but not all of the components of the tutorials. Our analysis aims to establish two points:

(i) A TA's lack of buy-in directly affects his instruction, including his in-the-moment interactions with students; and

(ii) This instructional effect can stem from comparatively subtle, fine-grained lack of alignment with the developers' intentions. The lack of buy-in need not be a blanket rejection of the entire tutorial approach to instruction.

Oscar is a UM physics graduate student who taught the introductory physics course for three semesters during his first two years of graduate school. He feels a sense of responsibility toward his job and wants his students to succeed. He was initially assigned to the introductory course, but he chose to teach tutorial-based courses two more times. In his interview, he explains that his initial experience teaching tutorials better prepared him to ask students questions that could help them and that he considers the class more fun than doing problems at the board, as he would have done in a typical recitation section. In addition, he expresses concern that students did not learn as much as they could from the class because they did not pick up their graded homework from him. So, although Oscar does not buy into many components of the tutorials, this is not due to a dislike of his job or a lack of concern about his students and their learning.

4.6.1 Oscar's expression of his tutorial values in interviews

Oscar values some parts of tutorials: he considers group work, conceptual understanding, and the role of the TA as a questioner to be important aids to student learning. However, he does not buy into some aspects of the tutorials that the developers consider essential, including the value of starting with and refining everyday thinking when learning formal physics concepts and of TAs continuing to learn both physics and instructional methods. (An indication of the amount of Oscar's buy-in is found in Appendix 1 in the column labeled "O.") Oscar's lack of buy-in is in some ways subtle: a cursory inspection of his teaching practice would show a TA who sometimes questions his students as they work in small groups and who at other times patiently waits at a side table while students work through the tutorials on their own. But, as we demonstrate in the section following this, the tone he establishes and the message he sends to his students with respect to the tutorials are profoundly different than what the developers intend.

4.6.1.1 Values some basic premises of tutorial learning

4.6.1.1.1 Group work

In his interview, Oscar says, “Group work, I think, is very beneficial in that people are actively thinking about it. If they're working on a homework problem together, they can, you know, they can curb each other’s stumbling blocks and explain it to each other. And, you know, once you're explained something to somebody, it's a lot easier to understand it yourself.” Oscar believes that group work helps students with difficulties because their classmates can assist them and because articulating ideas can help you learn them.

For Oscar, having a TA available is an important part of the group work. He says that the tutorial setup lets “…them work together, there, with a TA present, so that if they do as a group have a stumbling block, there's someone who can, who can get them all through it together. And then, probably just for enough so they can keep working on it on their own.” Thus, Oscar expects that students will encounter problems that can only be solved with the TA’s assistance; but the assistance should be minimal, “just enough” to get students unstuck. He also notes that he values group work in his own studies. He explains, “We're always working together on the homework… And it works, it works wonderfully.” The various reasons Oscar provides show that his level of buy-in to group work is quite deep: he perceives its value for students of any skill level, and he has experienced the benefits himself.

4.6.1.1.2 Comparison to traditional discussion sections

Oscar sees the tutorials as more beneficial to students than traditional problem-solving discussion sections. He said that such a discussion section would be a "boring problem for me, and they probably still don't get it." He saw tutorials as a way to elicit specific problems his students were having. He summarized his feelings by saying, "So overall, I think it's a good approach, it's a good method, and I bet it's effective."

4.6.1.2 Is ambivalent about some features of tutorial learning

4.6.1.2.1 Conceptual along with quantitative

Oscar values both conceptual and quantitative understandings of physics, but he thinks that because tutorials focus on conceptual learning, the students do not get practice integrating the two types of knowledge. He says, "I mean, every physics intuition I have, I'm almost certain I've gained by having a very vague idea at first, doing some problems, and then seeing how it relates. Going back to the idea, thinking about it a little more, in light of the results of these problems…." This quote also expresses Oscar's idea that solving quantitative problems is a way to create qualitative understanding. As he says, "I think if they just had the formula given to them… even if they don't understand it. Give them the formula. Give them some numbers to plug in. And they might see, oh, it doesn't really matter if there's this thing above it or not. And, I think if they got that kernel of wisdom, then they might start to think, oh, why is that?" Many physicists build up their qualitative understanding of the subject with minimal scaffolding while doing problem sets, so it may be that Oscar thinks that the best way for students to develop their conceptual understanding is by first working out quantitative problems, and then reflecting on the results, as physicists do. Thus, Oscar agrees that students need to develop a conceptual understanding of physics, and he sees it as a job they need to do themselves. Where he disagrees with the tutorials is the method by which students can best do this; We discuss this more fully section 4.6.1.3.1.

4.6.1.2.2 TA as questioner and coach

Oscar also expresses mixed feelings about the value of TA questions in student learning. In his interview, he said that it was important for students to work through problems themselves, rather than have the answer given to them. He felt that his questions could help the students if they provided a broader context for the problem the students were working on. However, he conveyed frustration with the use of questions in some instances. For example, in the TA training the TAs were told to paraphrase questions back to students. The purpose of this instruction was to provide TAs with a way of checking their understanding of the student's question, but Oscar said that graduate students were sufficiently prepared to comprehend students' questions and that this would only assist a student who "is so lazy that they really need to hear their own question repeated back to them to get them to think about it." At another point, Oscar also communicates disappointment that he is prevented from giving students answers directly, when he says, "Sometimes… they really just need to be given the answer. If they're just given the answer, you know, they know what to work towards, and maybe that's the bigger picture they need." Oscar's view here is nuanced: he does not think that giving students the answer will make everything clear. Instead, he wants to give students answers because he thinks that they can be a foundation upon which students can build their own understanding. By contrast, the curriculum developers, who included Scherr and Elby, were afraid that many students would simply accept the provided answer and move on, rather than building from it as Oscar intends. Although observations of Oscar's teaching show that he often questioned students, the interview suggests that he felt constrained by this method.

4.6.1.3 Does not value certain aspects of tutorial learning

As the past sections demonstrated, Oscar buys into tutorials at the coarse-grained level typically emphasized in professional development training offered to TAs. He agrees that small-group interactions, assisted by TAs, are an effective method for teaching, and he believes that TA questioning is sometimes a useful tool for helping students. However, there are aspects of the tutorials that Oscar does not value as much: the strategy of building from common sense ideas toward formal physics understanding, the need for TAs to continually learn more about the physics they teach, and the level of challenge appropriate for introductory students.

4.6.1.3.1 "Fake" concepts

As detailed in other publications (Elby, 2001; Redish & Hammer, 2009; Scherr & Elby, 2006), UM tutorials emphasize students' epistemological development by focusing on how their knowledge from everyday life and other subjects can connect to what they are learning in their physics course. In particular, tutorials encourage students to start with their everyday thinking and then refine that thinking toward a correct understanding of the targeted physics concept. Consequently, some tutorials may introduce concepts using non-canonical terms or encourage students to discuss whether they expect physics to make sense all the time or if equations should match their common sense. This aspect of UM tutorials is particularly jarring for many TAs, including Oscar.

Oscar expresses concern that asking students to use everyday experiences as a basis for building physics knowledge is not productive. Instead, he thinks that students more effectively learn when they are exposed to the scientifically accepted knowledge, which they must then make sense of and check against their everyday ideas. He cites a particular example in the sixth tutorial of the semester, which introduces the intuitive idea of "oomph." The students are told, "The more oomph something has, the harder it is to stop, and the more ability it has to knock things over." They are led through a series of questions that help them construct a formula for oomph, and are then told that "oomph" corresponds to momentum. Oscar proposes a different approach: "If they can all at least agree that oomph is something that's going to be called momentum, that's going to be something 'mv', I think that would kind of cement their thinking together." He adds, "But something like oomph, which is, ah, it's fake, it's nothing real. It's not even something people have a real concept of. And most of them have studied physics already." In this case, Oscar does not think that students' experiences from everyday life will help them understand the idea of momentum as it is used in the course. His comment suggests that he does not see value in using a noncanonical term and that he assumes students can find more meaning when given an equation as compared to when they generate the equation themselves, at least in this case.

4.6.1.3.2 TA as learner of physics

A TA could view the weekly tutorial preparation meetings as providing an opportunity to learn physics in a deeper way, as one CU TA mentioned he does. TAs who feel that doing tutorials helps them learn physics in addition to learning instructional techniques are in a better position to appreciate tutorials as they appear to the students. While Oscar doesn't discuss the preparation meetings during his interviews, his participation in these meetings indicates that he does not view them as a productive activity. In general, Oscar participates in the discussions about students, demonstrating that he seems to consider it appropriate to discuss difficulties regarding classroom management or particular content problems students have.

However, during the portion of the meeting where TAs complete the tutorial itself, Oscar does not regularly participate in the discussion about the correct answers to the questions or in discussions when TAs anticipate student answers, although he sometimes makes humorous, off-the-cuff remarks. In one preparation meeting, for example, Oscar is working with two other TAs on a tutorial about torque. Oscar participates minimally in the discussion: he answers the questions on the worksheet in a monotone, and sits slouched at the table with a neutral expression. His most animated contributions are jokes and critiques of how the questions are worded. At one point, Oscar takes the paper clips that the tutorial intends to be hung on a balance and forms them into a chain; he attaches a washer to the end of the chain and swings the assembly rhythmically back and forth. His activity makes the paper clips unavailable for their intended purpose, as another TA complains, "We need more paperclips. Stop being such a paperclip hog." Overall, Oscar's posture, tone, and activities communicate his feeling that the TA meeting will not be a useful experience for him.

4.6.1.3.3 Correct level of challenge for introductory students

Oscar is concerned that what the tutorials ask students to do is too difficult for them. He says, “So I think doing that continuously, you know, making the students expect to have to just trudge through all this stuff, that they, you know, that they don't really understand and not really sure where they're going, week after week is, is overtaxing on them.” Later, he contrasts the tutorials to repeated quantitative problem solving: “It's a mistake to try and force them into this new way of doing physics right away… They need to be eased in. You know, give them, give them ten plug and chug problems first. Just so they can get used to doing some of the math and some of the concepts.” Oscar is not buying into the tutorials’ assumption that introductory students, some of whom are accustomed to problem solving by rote, can adapt to a style of learning which requires them to be active participants.

As shown in the earlier section on group work, Oscar buys into the idea that students need to construct their own physics knowledge. He thinks that students teaching themselves is “really the only way to really learn something.” However, he believes that students need different amounts of assistance from a TA in order to build that understanding. He explains, “For particularly good students, I think that they have the potential from the beginning to just think through things, and giving them the answer might satisfy them temporarily, but not really get them thinking… But I think for students maybe in the middle, sometimes just being able to tell them, ‘Listen, this is how it works…’ I think in some cases that would help.” While Oscar believes that successful learning only takes place when students do the work themselves, he doesn’t think that the average student can do that work without help from the TA. He believes that “help” can include providing the answer, and that “thinking through things” can include making sense of that answer.

These examples demonstrate that Oscar cannot be simply classified as buying in or not buying in to tutorials, because his support for the tutorials depends on the particular attribute being considered. In particular, he views the tutorials’ focus on conceptual understanding as important and he values group work, in part because it fits with his epistemological ideas that students must construct their own knowledge. However, he disagrees with the particular epistemology enacted by the UM tutorials: that learning physics is the refinement of everyday ideas and should therefore start with everyday ideas. It is likely that tutorials based on more formal concepts would get more buy-in from Oscar.

4.6.2 Oscar’s expression of his tutorial values in the classroom

The next two sections examine samples of Oscar’s classroom interactions and how his buy-in (or lack of buy-in) of specific tutorial attributes influences his instructional behavior. The observed interactions occurred in the tutorial classroom during the semester Oscar was teaching tutorials for the third time.

4.6.2.1 Newton’s Third Law tutorial

In this episode, Oscar’s class was working though a tutorial that helps students reconcile the idea that two colliding objects each feel the same force (Newton’s Third

Law) with the “common sense” idea that a larger truck causes more damage to a smaller car when they collide than vice versa (Elby, 2001; Elby, et al.). The tutorial begins by considering the collision of a truck and a stationary car. The students were asked to use their common sense to generate a guess about which vehicle experiences a greater force. After the students read an explanation of Newton’s third law, they applied the law to the situation and then observed two carts colliding, with force probes attached, as a demonstration of Newton’s Third Law. The tutorial then poses the question excerpted in Figure 1. A correct answer would be that the car gains 10 m/s because it weighs half as much as the truck and so it will react twice as much.

> Before accepting that there’s an irreconcilable contradiction between Newton’s third law and the intuition that the car reacts more during the collision, let’s try a reconciliation strategy called *refining your intuitions.*
>
> We’ll start with a new question. Suppose the truck’s mass is 2000 kg while the car’s mass is 1000 kg, and suppose the truck slows down by 5 m/s during the collision. Intuitively, how much speed does the car gain during the collision? (Apply the intuition

Figure 1. Excerpt of the UM tutorial on Newton's third law

4.6.2.1.1 Instructs all students to disregard the term “common sense”

Oscar communicates his lack of buy-in to the tutorials with instructions he gives to his class. At the start of this tutorial hour, Oscar instructs the whole class: “In part one, it says 'common sense,' feel free to replace that with 'a guess'. Um, when I, when I went through this I thought this isn't common sense at all.” This instruction conflicts with the intention of the tutorial, because the tutorial deems the “common sense” idea that the smaller car will be more damaged as a reasonable idea that students will likely hold, and requires that this idea not be discarded, but rather reconciled with Newton's Third Law.

Oscar’s exhortation here aligns with his beliefs regarding the usefulness of intuition when learning physics. His correction is aimed at the tutorial’s intention to encourage students to refine and build on their common sense ideas. In his interview, Oscar expresses his belief that everyday ideas are simply different than physics ideas, and that the time to reconcile (to the extent possible) is *after* the student has learned and practiced using the formal concepts. When he tells his class to “guess,” he may be suggesting to them that their task is to fill in a space on a worksheet, not generate an idea on which they can productively build.

4.6.2.1.2 Declines the opportunity to support particular students’ common-sense reasoning

In another episode, a group of four students has called Oscar over and told him that they think the answer to the exercise above is 10m/s. Oscar affirms this and then asks them “Why?” which leads to the following conversation. The students offer their reason that “the car is half,” which Oscar interprets as saying the car has half the mass of the truck. He prompts them to think about quantities that are the same and different before and after the collision. The students then answer that the force is the same and the things that differ are velocity and acceleration, which Oscar then connects to the equation F = ma.

S4: The mass, the mass that describes it…
Oscar: They're-
S4: One is, the car is half. Yeah.

S2: One is twice as much
Oscar: Right. Okay, so they're different masses.
S1: Right.
Oscar: Meaning…
S2: They're going to have different… um…
Oscar: I mean, you're on the right track.
S2: Do you want us to talk about inertia? Or…
Oscar: Uh, inertia is a little, just a little bit beyond this. I mean, if you can think of it in terms of inertia, that's fine. But that kind of, uh, makes answering these questions harder. The basic problem in pretty much every last physics question you'll ever answer is to figure out what's the same and what's different. Either before or after. So in this situation, what's the same?
S2: The force.
Oscar: Okay, and what's different?
S2: The mass.
Oscar: Is that it?
S4: The velocity.
Oscar: And the - is that it?
S1: Yes.
S2: I don't know.
S1: No.
Oscar: No. You're on the right track. You're close.
S2: I feel like this question is designed to make us feel stupid.
Oscar: Ah, yeah. They are, they are. That's why I told you guys, don't worry about calling it common sense. It's a guess.
S1: Right.
Oscar: Right?
S2: Um…
S4: Friction?
Oscar: Say what?
S4: Friction?
Oscar: The what?
S4: Friction.
Oscar: Oh, no, no, don't worry about friction here.
S2: The acceleration, maybe?
Oscar: Yeah. Right. So what is, do you guys have a formula for the force?
S3: Ah, mass times acceleration.
S4: Acceleration.
Oscar: Yeah.

Oscar guides the students to the reasoning that he considers appropriate, rather than the reasoning that the tutorial is trying to elicit. After the interaction discussed here, he eventually prompts the students to say that because the forces are the same, and because force is equal to mass times acceleration, the fact that the mass of one of the objects is greater means that its acceleration must be less. Here Oscar is using the idea that the forces are equal and the relation that force is equal to the product of mass and acceleration to show that in a collision, one object could have a greater acceleration than the other if its mass is smaller.

The instructional moves Oscar makes in this episode align with his epistemological belief that everyday ideas are not a useful foundation for building physics knowledge. The students' answer of 10 m/s, supported by their commonsense idea that the car will speed up twice as much as the truck slows, because the car is half as massive, is a response that the tutorial developers consider appropriate. The students' ideas about inertia or the difference in the vehicles' masses, if elaborated, would also be approaches that could feed productively into the subsequent exercises in the tutorial. Oscar, however, rejects the students' ideas as insufficient because he does not buy in to the idea of intuition refinement. Instead, he expects a compensation argument between mass and acceleration with respect to the equation F = ma. The tutorial also (eventually) wants students to make this argument, but it wants this to connect to their commonsense idea that the car speeds up twice as much as the truck slows down, a connection that Oscar does not value.

Oscar's intervention here also aligns with his beliefs that physics knowledge needs to be constructed by making sense of equations. Our observations of his teaching in other tutorials show that he does not often alter tutorials in a broad way, as he does by announcing this change to the entire class. It seems unlikely that he has made this change simply because he enjoys modifying tutorials or because he is responding to a specific student's need. Instead, the change that he has made aligns with his beliefs about how physics should be taught.

4.6.2.1.3 Positions himself away from the tutorial developers

In the encounter described above Oscar positions himself as separate from the tutorial developers, who designed the questions that make the students "feel stupid." By agreeing with Student 2's assessment, Oscar indicates that he does not think that what the students are being asked to do will help them. He is not introducing this attitude to the group; before Oscar approached the group, the Student 2 had remarked, "They're assuming that we’re a lot dumber than we really are,” and other students made comments that supported this sentiment. Even so, Oscar reinforces the students’ discomfort by implicitly telling them, through his questioning, that they are not approaching the problem the right way.

4.6.2.2 “Oomph” Tutorial

We analyze another exchange that occurs when Oscar’s class is working through the sixth tutorial of the semester, which introduces the concept of momentum. As discussed in the section examining Oscar’s valuation of tutorials, this tutorial introduces the intuitive idea of “oomph” and then asks students to develop a formula to represent its dependence on mass and velocity. It then connects that concept and formula to the formal idea of momentum. Example collisions give students the opportunity to show that the equation matches their intuitive ideas.

In the episode below, the students have completed the first third of the tutorial and reached a point where they are supposed to consult with their TA. They wait about ten minutes, at which point Oscar notices that they are not working and approaches them. He asks what momentum is, and the students respond that it is ‘mv’. He asks for more reasoning, and they explain why they would expect momentum to depend on mass and velocity. Oscar acknowledges this and discusses why it makes sense that the two quantities are multiplied (instead of divided, for example.) He then draws their attention to the fact the momentum is a vector quantity. In the second half of the episode Oscar introduces examples to focus on why momentum depends linearly (as opposed to quadractically, etc.) on mass and velocity.

Oscar: How are you guys coming along?
Are you about at a checkpoint?
S1: I think so.
S?: Yeah. [2 second pause]

Oscar: All right, so what's, uh, what's momentum?

S1: P.

Oscar: Okay, P equals…

S2: mv.

S1: mv.

Oscar: Okay. And why mv?

S1: Because it depends on the mass and velocity.

Oscar: Okay. That's a good start. So some function of mass and velocity. Why is it, why is it m times v?

S1: Um…

S4: Cause you're measuring how, how the, how something is moving-

Oscar: Okay.

S4: - towards the same direction. So the components would be the mass of the thing that's going and how it's moving, which is the velocity. [3 second pause]

Oscar: Right, but why're they in that, the question is why are they in that particular relationship. What happens if you, if you just change the mass, but leave velocity the same?

S2: The momentum will change?

Oscar: Right. Right, let's say you double the mass, how's the momentum change?

Students: Doubles.

Oscar: Right. You double the velocity, and…

S3: Double.

Oscar: Yeah. Doubles. As long as you keep the mass the same. Right. So, so, they're somehow on equal footing, right? So I mean if you divided one by the other, that wouldn't really make as much sense. If you subtracted one from the other, I mean, I didn't mean [inaudible] it just wouldn't make any sense.

S1: Yeah.

Oscar: So you think of it as mv. Um, what kind of number is p?

S4: Um…

Oscar: Scalar, vector, tensor, bilinear?

S4: Vector.

S1: Vector.

S4: Vector.

Oscar: Vector? Why is it a vector?

S1: Cause it has direction.

S4: Direction.

Oscar: Well, a lot of things can have direction. And they don't have to be vectors.

S1: Um, and a magnitude?

Oscar: Say what?

S1: And a magnitude?

Oscar: Yeah, exactly. Yes, it's pointed and it has magnitude. Well, it's, it's important. I mean, you can, you can point-

S1: Yeah, right.

Oscar: - in some direction, like an angle. Like an angle is pointed in some direction, but it's not a vector, right. All right, so, um, the example I've been talking with everybody else about is, um, the bowling balls, if you have two identical bowling balls and you, and you push them off with the same velocity. Each one has momentum p, right. How much is p?

S1: How much is p?

Oscar: Yeah.

S1: It depends on their masses.

Oscar: Okay, let's say it has mass m and velocity v. How much is, uh, the momentum of one bowling ball?

S4: mv?

Oscar: Yeah, mv, right? Okay, now you have two of them, right? So what's the momentum of each one of them? They're identical bowling balls moving at the same velocity in the same direction.

S1: Two mv?

Oscar: Okay, so two, so is that, so is that for one of them now, or both of them together?

S1: Both of them together.

Oscar: Together, right. Right, so I mean, if you have each one of them going, doing the exact same thing, same mass, and you step far away, back enough-

S1: Mm-hmm.

Oscar: You know, you look at it, you can't tell them apart, right?

S1: Yeah.

Oscar: But you can say, well, you know, it's just got a total mass of …[3 second pause] What's the total mass?

S1: Of two m.

Oscar: Two m, right? But your velocity's still the same?

S1: Yeah.

Oscar: Or different? Yeah. So same, same velocity, twice the mass, so that's the total momentum.

S1: Got you.

Oscar: So the question is, then, so you can break it up that way for mass. How can you break it up for velocity?

S1: I don't know.

Oscar: Any ideas? [13 second pause] I can't. I can't think of any, well I can, but it's a really weird thing. If I use, it's, um, if you have, if you have advanced calculus, there's a way to do it. But I mean it doesn't really make much sense. Right?

S1: Right.

Oscar: It's like, you know, I mean mass you can imagine, okay, so I have one pen and two pens. Those are two different masses, right?

S1: Yeah.

Oscar: Right, I can put them together and they got a total mass, but you can't really do that with velocity.

4.6.2.2.1 Links physics and everyday experiences in a different way than the tutorial developers

The length of this episode is necessary to understand what Oscar is doing, because the purpose of his questioning is apparent only at the end of the episode. At the start of the interaction, Oscar is asking questions about the momentum equation. These questions elicit the students' reasoning about what momentum depends on (mass and velocity) and why the students would expect those quantities to be multiplied rather than divided or subtracted (Lines 1-45). This is aligned with the intentions of the tutorial, which aims to help students identify their intuitions about momentum and then relate them to physics. However, after this series of questions (and a short diversion into the definition of a vector), Oscar spends a significant portion of his time (a full half of the four minutes he is at the table) discussing an example that he introduces. By the end of the example, we can see that the purpose of it is to show the students why momentum should depend *linearly* on mass and velocity. This relationship is not emphasized in the tutorial and there is no indication that the students are particularly concerned about it, but the amount of time he devotes to discussing it shows its importance to Oscar.

Oscar's focus on the linear relationship of mass and velocity in the momentum equation demonstrates the difference in how he and the tutorial developers view the role of common sense in physics. As discussed in the previous example, Oscar does not consider common sense ideas to be a sufficient foundation for building physics knowledge. While this tutorial seeks to begin with common sense ideas of momentum and then relate them to the equation, Oscar wants students to begin with making sense of the equations and then to check that they are consistent with everyday life. There are many ways Oscar indicates that common sense is not the correct starting point. He asks the students about "momentum" and does not use the word "oomph." (Line 6). He prompts them for the equation, rather than a conceptual explanation: when the students say that momentum is "p," Oscar asks what "p" equals, not what p is (line 8). He discusses examples, but includes an example, dividing momentum into two separate velocities (lines 113-122), which is nonsensical. These actions allow Oscar to show the students that the equation can be connected to their everyday experiences, but only after they have mathematically understood the formula for momentum.

4.6.2.2.2 Provides the assistance he thinks students need to construct their own knowledge

Because Oscar believes that tutorials are too difficult for his students (as he made clear in his interviews), his role in his conversations with students is to provide some of the scaffolding steps for them to complete their assignment. In both of the examples of Oscar teaching, the conversation is directed by him; he asks the questions and the students provide the answers. He introduces the situations he would like to discuss and questions the students to highlight the points he thinks are important. In the previous example this includes the idea that momentum is a vector and that it is linearly dependent on velocity and mass. By directing the flow of conversation, Oscar can "take them by the hand and lead them through the steps at first," a course of action he thinks is necessary to counteract the tutorials' overestimation of the students' abilities.

In his interviews Oscar also discussed the role of the TA as providing necessary information for the students. He values group work because students can help answer each other's questions, which helps both the questioner and answerer learn. But he also thinks that when the entire group encounters a question that they cannot answer it is the job of the TA to help them through it. His view that the TA's role is to help solve problems too challenging for the group may explain why he asks questions with specific answers rather than asking open-ended questions.

4.6.2.2.3 Uses questions to guide students

We also see Oscar acting in accordance with the aspects of tutorials that he does value. In both of the episodes above, as in most of his interactions with his students that we have examined, Oscar questions his students, rather than delivering "mini-lectures." This is consistent with his idea that students need to build their own knowledge and that questions are one of the ways TAs can assist students. While the same information can be imparted to students through a mini-lecture or the style of leading questions that Oscar uses, Oscar's choice of guided questions reflects his belief that if you tell students, they only receive the information once, but if they figure it out themselves, they can recreate that knowledge whenever they need it. Oscar is attempting to scaffold his students' construction of physics knowledge, but because he has specific goals of what he wants them to learn, the conversations he leads are quite rigid.

The previous section's examination of Oscar in the classroom shows the way his buy-in affects his classroom practice. His belief that students should construct their own knowledge leads to his frequent use of questions in student conversations. The fact that he expects particular answers to these questions can be connected to his idea that a TA needs to provide concrete help when a group is stuck and to his view that tutorials are too difficult for students. His focus on building physics meaning from equations rather than everyday experiences causes him to modify the focus of a tutorial. Oscar's specific beliefs about reform instruction can be connected in a fine-grained way to his instructional moves in a way that could not be captured, say, by a survey or observation protocol that classifies instructors along a constructivist/ transmissionist spectrum.

4.6.2.3 The interaction of buy-in and teaching practice

In the two episodes presented here, Oscar's beliefs affect his actions. However, as discussed at length in other work (Goertzen, Scherr, & Elby, 2009), we are not telling a causally unidirectional story of beliefs driving behavior. Oscar's framing of his interaction with his students also gets stabilized by feedback loops that form, over both short and long time scales, between his beliefs, his focus of attention, and his actions. The Newton's third law tutorial, discussed above, provides an example. Believing that refining everyday thinking is unproductive, Oscar tells students not to take seriously the tutorial's call for "common-sense" reasoning. When he later interacts with a group of students, he glosses over rather than further eliciting the students' initial intuitive reasoning about less mass leading to a greater change in velocity (Section 4.6.2.1, lines 1-8). Then he rejects the students' request to talk about inertia (lines 12-18), which also might have connected to the students' common-sense ideas about the effects of less mass/inertia (lines 12-18). What he notices and amplifies instead is students' protestations that the questions "make us feel stupid" and their ability to figure out answers in response to his questions (e.g., lines 50-54). Oscar's beliefs "filter" his attention in a way that he does not fully "hear" or follow up on students' productive common-sense reasoning; instead, he hears student utterances supporting his view that leading students through his (as opposed to the tutorial's) way of approaching the topic is productive. In this way, a feedback loop begins to form between his initial beliefs about the inefficacy of building physics concepts from common-sense ideas, his lack of attention to common-sense aspects of students' reasoning, and his guided-Socratic approach to questioning. Oscar's belief helps to cause the lack of attention (why attend to something that is unhelpful to students) and the lack of attention ensures that he does not "hear" student reasoning that would challenge his belief — i.e., students productively building on common sense. His belief also helps to drive his Socratic questioning, which then supports his belief; he sees students arrive at correct answers to his lines of questioning, and does not see — because his Socratic questions do not give students the opportunity to express — productive common-sense reasoning that could be built upon. These bidirectional causal links between Oscar's beliefs, attention focus, and actions lead to a stable local coherence in his epistemological (and social) framing of his activity. The formation of this stable frame is part of the mechanism by which Oscar's lack of buy-in (as encoded in certain beliefs) leads to instruction contrary to the developers' intentions.

4.7 A comparison of TA buy-in across two institutions

The above example shows how a TA may communicate his perceptions of the tutorials' value to students in his classroom, thus supporting or undermining the tutorial process. We have found that at the University of Maryland, most TAs do not buy into at least a few aspects of tutorial instruction, and this lack of buy-in aligns with their behavior in tutorial. As part of our research we wanted to better understand what contributes to TAs buying into tutorials, so as to better foster that in their professional development. For this purpose, we visited an institution at which most TAs seem to regard the tutorials as valuable and worthwhile (CU). We spent four weeks interviewing TAs and observing and videotaping the tutorial system there, including TA preparation sessions and multiple tutorial sessions.

To better characterize the TAs' buy-in, we examined the statements TAs made about tutorials in their interviews. We categorized those statements and produced a chart summarizing each TA's degree of buy-in to eight aspects of the tutorials discussed by the TAs during interviews. (These were aspects such as such as group work, conceptual emphasis, level of challenge, and so on). Appendix 1, which also discusses our coding methods, shows results for fifteen UM TAs and four CU TAs.

A comparison of TAs' responses at the two institutions shows distinct differences. One-third of the UM TAs did not buy into one half or more of the attributes of tutorials. The CU TAs made comments that indicated their buy-in or mixed feelings about the majority of the tutorial attributes. A significant portion of UM TAs did not buy into two aspects that tutorial developers consider particularly important: the focus on qualitative reasoning and the importance of intuition in building physics knowledge. In contrast, the only category that CU TAs were predominantly not bought into reflects their concerns that tutorial questions are not always clearly worded, a concern that does not seem as critical to the successful implementation of tutorials as support for the content is. These findings support our initial observations that there is more buy-in at CU than at UM.

4.8 The effect of tutorial social and environmental context on TA perceptions of the tutorials' value

A small number of studies examine the effects of social and environmental context on individual instructors. While none focus on TAs, research examining the effects of social and environmental context (variously termed the teaching environment, department-level culture, or situational characteristics) on professors and teachers has produced findings consistent with those presented in this paper. A large-scale survey of Australian professors found evidence that departmental policies and values affected chosen teaching approaches, such as the degree of focus on students (Ramsden, Prosser, Trigwell, & Martin, 2007). Professors have also identified these influences on their teaching approaches and priorities in interviews (Knight & Trowler, 2000; Prosser & Trigwell, 1997). A more detailed look at contextual effects on individual teaching practices is found in Henderson and Dancy (2007), who found that teachers' conceptions of teaching were more aligned with reform instruction than their teaching practices (a finding supported by a multitude of K-12 teacher studies)(Bryan, 2003; Cohen, 1990; Jones & Carter, 2007; King, et al., 2001; Simmons, et al., 1999; Tobin & McRobbie, 1997); the instructors were often aware of this inconsistency, which they explained by citing constraints of the context. These studies all assessed the instructors' perceptions of the context, in contrast to this study, in which descriptions of the social and environmental context are generated by the researchers.

The following section details the differences in tutorial social and environmental context that we have noted during our studies of CU and UM, which we feel can plausibly explain the differences in TA buy-in at the two institutions. The tutorial programs at UM and CU are in many ways very similar. As described in previous publications (Finkelstein, Otero, & Pollock, Fall 2006 - Spring 2007; Finkelstein & Pollock, 2005; Pollock & Finkelstein, 2008), students attend a one-hour weekly tutorial in place of the discussion section as a component of the introductory year of physics courses. The TA professional development programs at these institutions are not described in detail in published literature (Finkelstein & Pollock, 2005; Redish & Hammer, 2009), but are also similar, bearing a strong resemblance at least superficially to the program at University of Washington (UW) on which both are based.[5] Both programs employ physics graduate students mainly in their first and second years of studies and rely primarily on students who are not affiliated with their respective PER groups. The backbone of the professional development program is the weekly tutorial preparation sessions that are required for all TAs. During these sessions, TAs work though each week's tutorial themselves, learning the physics as well as the issues students commonly face with the material. Experienced TAs and faculty model effective instructional practices.

We have shown that, in spite of the apparent similarities in their situations, TAs at CU buy into the tutorials more highly than those at UM. In what follows, we describe the aspects of the two systems that seem to affect the experience of being a tutorial TA at each institution. In this section, unlike previous sections, we are not documenting specific

[5] The tutorial preparation in the first year we collected data was conducted by one of the authors, Rachel Scherr, who has extensive experience conducting TA tutorial preparation programs at UW.

causal connections. Instead we are noting the differences in institutional environments and making plausible arguments about their effects on TAs. We follow Pollock and Finkelstein (2008) in considering five levels of implementation of the tutorial program: levels of task formation, the classroom situation, the course culture, the department, and the university. In each case we observe the differences between UM and CU implementations that seem to affect the value that TAs place on tutorials. These differences are summarized in Table 1.

4.8.1 Task formation

4.8.1.1 Production value

Because CU uses the professionally published *Tutorials in Introductory Physics* and UM uses locally developed tutorials, there are a number of differences between these curricula that would be apparent even to TAs unfamiliar with the development of each set of tutorials. Most obviously, one is professionally published and one is inexpensively bound by the local copy center. We speculate that these features may contribute to TA buy-in at CU because the tutorials there appear to be (as they are in reality) a research-based curriculum developed by another institution and distributed to an extensive number of institutions, while the UM tutorials may be perceived as a pet project of the local PER group.

4.8.1.2 Level of difficulty

The content of the tutorials is also different in the two cases. The tutorials used at CU are calculus-based and are typically longer. They are more difficult for students to complete, and are in fact designed so that no student group will finish and be unoccupied during part of the period. In contrast, UM tutorials were written for use in an algebra-based course and it is not unusual for some student groups to complete the entire tutorial during the session.

4.8.1.3 Purity of physics content

The CU tutorials are more exclusively physics-oriented than UM tutorials, whose epistemological emphasis allows for inclusion of questions that encourage students to reflect on their learning processes as well as on the physics concepts. The explicit epistemological component of the UM tutorials is salient for the TAs using them. In interviews where TAs discuss their tutorial experiences, one UM TA talked about a tutorial activity in which students are asked to consider their own ideas about learning physics: “I mean – well, physics is really a very precise science, right? So I mean people’s opinion doesn’t matter that much. So I mean they should – I mean it’s better if they have the impression that there is actually something that’s absolutely right in physics.” Comments like this show that the epistemological component of the UM tutorials can be perceived as too easy, a poor use of time, or even harmful for students. In comparison, CU TAs do not remark on the exclusive focus on physics in the tutorials they use. TAs' lack of familiarity with explicit epistemological instruction may cause them to value it less, leading to less TA buy-in at UM.

All of these features contribute to TAs valuing the tutorials used at CU more highly than those used at UM. The tutorials used at CU are professionally produced, more challenging, and not diluted by questions that are not specifically about physics. These tutorials are also more formal, in the sense that they do not introduce non-physics terms such as “oomph” and they don’t end a section before a formal concept has been developed.

4.8.2 Level of situations

4.8.2.1 Classroom location and appearance

The classroom contexts for the tutorials at the two institutions are also different. At UM, all tutorial sessions (about twenty in the course of a week) are all held in the same classroom, a windowless, minimally maintained lab room off a little-used hallway with a capacity of about 24 students. At CU, tutorials are held in a large room divided into bays; each tutorial session takes place among other simultaneous tutorial sessions in a crowded, open, noisy setting connected by a well-traveled corridor. The CU setting potentially displays the tutorials as being a highly central and communal experience, something that many others are actively engaged in at the same time. The UM setting, in contrast, is isolated from other physics instruction happening in the building. Figure 2 shows the two rooms.

Figure 2. The photo on the left shows the UM tutorial room. The photo on the right shows the CU tutorials, which are conducted in three adjacent bays.

4.8.3 Course culture

4.8.3.1 Attendance requirement

The TAs' perceptions of the tutorials are also influenced by how the courses are structured at each institution. Participation in the tutorials is required at CU; a small percent of the students' grade is based on this participation. At UM, tutorial attendance is recommended, but no credit is given and the amount of encouragement to participate varies among lecturers.

4.8.3.2 Representation on exams

The emphasis on the conceptual reasoning practiced in tutorials is also different. At UM, exam questions based on tutorial material are available to all lecturers, but are mainly used by those faculty affiliated with the PER group. At CU, questions on tutorial material generally comprise 25% of each exam grade and both TAs and students are aware of this. Together, the lack of attendance credit and dedicated exam questions lead UM TAs to discount the importance of tutorials. This difference in perception was reflected in the way TAs evaluated the tutorials' "fit" with the rest of the course components. At UM, three-quarters of the TAs described the tutorials as disconnected from the rest of the course or as not preparing students for their exams or homework. In contrast, only one CU TA raised the issue, and he believed that the tutorials provided preparation for a sizeable component of the course assessments.

4.8.3.3 Student population

The student population of each class varies as well: at CU, the tutorials are used in the calculus-based introductory courses for engineering and natural science majors while the UM class is algebra-based and taken by pre-meds and biological science majors. This difference may result in TAs more highly valuing instruction that is more math-intensive and is offered to physics students.

4.8.3.4 TA preparation meetings

At both institutions TAs attend weekly meetings to prepare for the following week's tutorial. The CU tutorial supervisor was a researcher, not associated with the PER group. The UM tutorial supervisor was a PER researcher one year and an unaffiliated postdoctoral researcher the second year. A cursory overview of the meetings at CU and UM would not reveal any startling differences. In each, the tutorial supervisor introduces the tutorial and sometimes leads a discussion. Then the TAs work in small groups, as their students will, to answer the questions on the worksheet while the tutorial supervisor circulates, modeling the instructional practices he or she would like the TAs to use.

A more detailed examination shows important differences. To illustrate this, a video clip of a TA group in each university's preparation session was selected and the clips were compared. While we attempted to choose video clips that seemed representative, the clips were not chosen randomly and the selection could have been influenced by researcher preconceptions. In the UM clip, three TAs answer the questions on the worksheet and do some of the experiments described in the tutorial. While they offer comments and questions, the conversational turns are short and are rarely in response to other comments and they make little eye contact, so that there is minimal continuity in the conversation. None of the TAs writes anything on their worksheets and they do not work on the questions simultaneously. The objective of the TAs appears to be to become familiar with the exercises and equipment and it seems that perfunctory participation is sufficient to achieve this objective. In contrast, the CU clip shows two

TAs and two LAs answering the same questions at the same time. They discuss the question they are working on and respond to each other's questions and comments. There is more continuity in their conversation and they are attempting to answer all the questions on the tutorial. The tutorial appears to be taken seriously as a way that they can better understand physics and as a challenging experience for their students for which they need to prepare. We conjecture that because UM TAs buy into the tutorials less thoroughly, their attitude is one of the factors that make the meetings worse; the decreased quality of the meetings then negatively impacts other TAs in a feedback loop. The striking observation, though, is the distinctly different TA behavior that occurs in spite of the similar structure of the two meetings. Because the meeting agendas are so similar, it seems likely that social and environmental context aspects beyond the preparation sessions affect the TAs' actions.

4.8.4 Department level

4.8.4.1 Nature of TA assignment

At the departmental level, a distinct difference between the two tutorial implementations is that CU TAs assigned to teach the introductory course teach multiple tutorial sections, but no lab sections. They are responsible for grading only tutorial homework and class exams. At UM, a TA with a full TA assignment typically teaches two tutorial sections and four hours of lab and grades lab reports, tutorial homework, quantitative homework, and class exams. As a result, the tutorial instruction is only a fraction of a UM TA's responsibilities. It is possible that this contributes to lower UM TA buy-in, and at a minimum it requires them to divide their attention. In addition, because first-year UM TAs attend a mandatory department-wide professional development meeting, a first-year tutorial TA at UM attends three and a half hours of weekly preparatory meetings, while a CU TA attends one and one quarter hours weekly. The large amount of mandatory meeting time for TAs of this course leads to it being informally considered a heavier teaching load than the average TA assignment, and it is possible that this also contributes to lack of TA buy-in.

4.8.4.2 Support by regular faculty

The CU implementation has achieved a higher level of independence from the PER group that advocated their introduction as compared to the UM execution. At CU, the lecturer of the course associated with tutorials is not a member of the physics education group, but is informed about and supports tutorials. During the month that we observed, he often appeared at the TA preparation sessions. The tutorial supervisor was a researcher, not associated with the PER group, who ran the preparation sessions competently. At UM, there are typically three lecturers teaching the introductory course that uses tutorials. The majority of these lecturers are non-PER and they consider tutorial preparation to be solely the responsibility of the tutorial supervisor. In addition, the position of tutorial supervisor, which in the earlier years was filled by a member of the PER group, was assigned during the second year we collected data to a postdoctoral researcher outside of PER who had no previous experience with tutorials.

4.8.4.3 PER group involvement

Another factor that may communicate the department's support of tutorials to the TAs is the involvement of PER graduate students as tutorial TAs. At UM, PER graduate students often volunteer to teach tutorials. At CU, one or two PER graduate students who don't have research positions yet may be assigned to teach tutorials, as any unfunded graduate student would. The fact that one-third of the tutorial TAs at UM can be affiliated with PER may contribute to the UM TA's perception that tutorials are a PER-supported project rather than one supported by the whole department, as at CU.[6]

4.8.5 University level

4.8.5.1 Interdepartmental reform effort

Support for reform instruction is also present at the university level at CU. Their Learning Assistant (LA) program (Finkelstein, et al., Fall 2006 - Spring 2007; V Otero, et al., 2006; Pollock & Finkelstein, 2008) selects students who are high achievers in the introductory classes to assist TAs in teaching tutorials. The physics LAs also take a course with LAs from other STEM disciplines, in which they reflect on their teaching and study teaching methods and theories of learning. The existence of this program, which provides an LA to teach with each TA in the CU tutorials, is one of the elements that may communicate to the TA the value that the university places on reform instruction.

4.9 Conclusion

Physics graduate students' beliefs about how physics should be taught affect their teaching. For example, Oscar's belief that knowledge construction should begin with equations leads him to disregard students' common sense ideas and his belief that TAs should provide concrete help leads to his guided-Socratic questioning. The example of Oscar's teaching suggests that buy-in is a necessary (but insufficient) component of effective curriculum implementation.

---

[6] The involvement of numerous PER graduate students in tutorials does not necessarily lead to a lack of TA buy-in. At the University of Washington, all PER graduate students teach tutorials throughout their graduate careers, in an implementation of tutorials that has lasted almost two decades.

Level of implementation	University of Maryland	University of Colorado	Likely effects on TAs
Task	•Locally produced •Algebra based •Often finished within allotted time •Uses informal terms such as "oomph" to connect physics to everyday understanding •Explicit epistemological focus	•Professionally bound •Calculus based •Not finished within allotted time •Rigorous use of vocabulary and concepts •No explicit focus on epistemology	TAs may buy in more to tutorials they perceive as challenging, rigorous, and undiluted.
Situation	•24 student room •Off an isolated, little-used hallway	•Room divided into bays where multiple tutorials occur at once •Large, bright, noisy room	CU tutorials are a highly communal experience; UM tutorial conveys a feeling of isolation.
Course culture	•Tutorial attendance only recommended, not required •No credit given for tutorials •Exam questions on tutorials rarely used •Students are primarily pre-med and biological science majors •TAs in prep meetings participate minimally	•Tutorial attendance required •Small amount of grade based on participation •Tutorial material is 25% of the exam •Students are primarily engineering and natural science majors •TAs in prep meetings demonstrate more authentic participation	TAs may buy into tutorials more when they directly affect students' grades and link to other parts of the class. Their participation in the prep meetings is consistent with their varying buy-in.
Department	•Tutorial TAs also teach and grade labs and two kinds of homework •Non-PER faculty may ignore (or disparage) tutorials •Tutorial teaching is informally considered a heavier teaching load •A significant number of the TAs are PER graduate students	•Tutorial TAs only teach tutorials and grade only tutorial homework •Lecturer and tutorial instructor are non-PER •Lecturer appears frequently at TA meetings	TAs may buy in more when they perceive the tutorials to be part of the accepted departmental practice.
University		Learning Assistant (LA) program trains undergraduates who assist TAs in tutorials	Institutional support can also be communicated through university-wide programs.

Table 1. A summary of the differences in social and environmental context at UM and CU and their likely effects on TAs.

The weekly, curriculum- based professional development programs commonly offered to graduate student TAs appear to have limited impact on the TAs' buy-in of the curriculum in use. These meetings, using a typical combination of pretests, FCI data, and working through tutorials, can help familiarize TAs with the content they will be teaching and with some typical difficulties students encounter when learning that material. While such preparation is necessary for effective teaching, it is not enough. The commitment to teach in a reformed manner and the skills needed to do that are also important. Our analysis suggests that these programs cannot instill the necessary valuation of reform teaching. A goal of our future research is to determine what sorts of activities would be most effective in scaffolding such values.

Effective professional development for TAs can be informed by detailed understanding of TA beliefs and motivations. Oscar, for example, believes that students should construct their own knowledge; a PD program well-suited to Oscar would build on that belief. It would also address Oscar's concern that tutorials are too difficult for students. Broad characterizations of TAs as "not buying in" risk obscuring valuable information about specific attitudes and skills that TAs already have.

The tutorial social and environmental context, including the classroom, departmental, and institutional environments, affects the beliefs that TAs at a particular institution hold. Greater attention to the development of supportive social and environmental context can help tutorial TAs value the tutorials they are asked to teach. The nature of this attention is likely to be specific to local circumstances. The analysis presented here suggests that TAs absorb the implicit attitudes of their colleagues and department. If TA supervisors ignore these implicit messages, TAs will be less likely to engage in effective reform teaching.

Chapter 5 Similar teaching behaviors are supported by varied beliefs about teaching and learning[7]

5.1 Introduction

The physics education community has devoted decades to producing research-based undergraduate curricula that help students construct their own physics knowledge. At the undergraduate level, there are now many successful, research-based curricula and instructional methods available (Heller & Hollabaugh, 1992; Mazur, 1997; McDermott & Shaffer, 2002; Sokoloff & Thornton, 2004). While the developers of these curricula have carefully studied how written material should be organized and how students should best interact with these materials, much less attention has been given to those who instruct using the curricula. At many universities, a significant portion of students' physics classroom instruction comes from the graduate student teaching assistants (TAs) who lead the discussion sections that supplement large lecture courses. There has been little published research on such instruction by teaching assistants, be it descriptive or prescriptive. Both researchers and doctoral students themselves have identified a need for more effective, research-based TA training for graduate students (Adams, 2002; Carroll, 1980; Golde & Dore, 2001).

Physics education research has demonstrated the benefits of understanding students' physics ideas before instruction so that we can develop lessons that build on them (McDermott & Redish, 1999; McDermott & Shaffer, 1992). Similarly, understanding the initial states of TAs provides the basis for professional development

[7] This chapter was previously pubslished in Goertzen, R.M., Scherr, R.E., & Elby, A. (2010). Tutorial TAs in the Classroom: Similar Teaching Behaviors are Supported by Varied Beliefs about Teaching and Learning. Accepted by Physical Review Special Topics - Physics Education Research, 6, 010105.

that considers the knowledge and resources that TAs already have. Research to identify TAs' teaching ideas and practices should ideally include both observations of TAs' specific instructional actions and reports from TAs of their goals and motivations, so that we may learn both what they are doing and what they are trying to do.

Our own detailed observations of TAs in tutorial classrooms have led us to identify a set of approaches to teaching that share a common characteristic we call "focusing on indicators." The indicators that TAs seek vary, but are all more superficial than detailed explanations - for example, key words, a particular type of reasoning, or correct answers. We find evidence that each TA's focus on indicators stems from his beliefs and attitudes about tutorial teaching. However, their similar behaviors do not stem from similar beliefs. Our primary finding is that different TAs with similar focus-on-indicator behaviors are motivated by different underlying values for tutorial teaching. For example, one TA in our study believes that students should be given the benefit of the doubt; another believes that students deserve to hear the right answer from the TA. In the classroom, however, these TAs interpret and respond to students' correct answers in a similar way.

The implications of this result for TA professional development are twofold. First, TA supervisors are not likely to be able to "read off" TAs' beliefs based on their teaching behaviors; there is not a one-to-one correspondence. Second, TA supervisors who want to help TAs value tutorial teaching should not expect to do so by guiding TAs' behavior: helping TAs learn to ask questions will not necessarily help them share tutorial developers' motives for questioning. The most promising means for improving TAs' teaching is to respectfully explore and engage with TAs' potentially productive beliefs about teaching.

5.2 Background

5.2.1 Previous Research

Research on graduate TAs is currently a small but growing field. In order to consider as much of the relevant literature as possible, this section includes research on TAs in all of the STEM (science, technology, engineering, and mathematics) disciplines. This research has rarely produced the sort of detailed descriptions of TAs' behavior that could inform professional development. Some professional development (PD) programs report changes in TAs' beliefs, but do not examine whether these result in changes in fine-grained behavior in their classrooms.

5.2.1.1 Much of the research on STEM TAs does not characterize their teaching

Much of the research on STEM TAs has taken place within studies of the professional development (Kezar & Eckel) programs for these TAs. These studies often focus on detailed descriptions of the content of the programs. The effects of these programs on the TAs are either measured through surveys, written assignments, or interviews that assess reported changes in the TA's attitudes about teaching or learning (French & Russell, 2002; Hammrich, 1994; Ishikawa, et al., 2001; Lawrenz, et al., 1992; Price & Finkelstein, 2006) or provide informal evaluations of TA experiences (Etkina, 2000; Hollar, et al., 2000). The studies using surveys have provided limited glimpses of TA changes after PD, including more appreciation of the importance of attention to student ideas (Ishikawa, et al., 2000), increases in beliefs that skills learned in teaching can improve their research (French & Russell, 2002), and more awareness of physics education research (Hammrich, 1994; Price & Finkelstein, 2006).

An example of a study assessing a PD program for TAs is Ishikawa et al. (Ishikawa, et al., 2000). The authors used written assignments and a free-response survey to assess the beliefs of two cohorts of TAs before and after a PD course and found that some TA beliefs changed. In the first cohort, they found that TAs were more aware of student difficulties and the responsibility of instructors to notice these difficulties. An example of the type of response demonstrating this awareness was one which said "…a good teacher is one who intuitively knows where students are going to have trouble in understanding a topic and is ready with helpful hints when they hit those bumps." (Ishikawa, et al., 2000, p. 6). In the second cohort, the researchers found that TAs were less likely to relate good teaching to the ability to communicate knowledge. This finding was based on the fact that this was mentioned more in the initial assessments than in the final ones. These evaluations show that how TAs talked about their teaching was altered, but they do not address the question of whether the TAs' classroom practice changed.

Surveys provide a way to assess larger groups of TAs and to identify shared knowledge or beliefs. However, a limitation of analyses built primarily on written materials is that they cannot address the question of how knowledge or beliefs affect practice. The use of self-reported classroom analysis is problematic not only because the TAs' self-reports may not accurately reflect their teaching practices, but also because it may be difficult for the researchers to identify influences that the TAs do not recognize themselves. Multiple studies in math and science education demonstrate that teachers' self-reports of their behavior and beliefs do not consistently correlate with their classroom actions (Bryan, 2003; Cohen, 1990; Jones & Carter, 2007; King, et al., 2001; Levitt, 2002; Simmons, et al., 1999; Tobin & McRobbie, 1997).

5.2.1.2 Observational studies in the classroom characterize TAs' teaching with broad categories

Observations of TAs' teaching have been used to assess the effectiveness of PD programs (McGivney-Burelle, et al., 2001; Robinson, 2000) and to better understand the TA or graduate experience overall (Belnap, 2005; Luft, et al., 2004). These observations are often limited to a few hours per semester and characterized by general descriptions of the TA's individual teaching style (Belnap, 2005; Luft, et al., 2004; McGivney-Burelle, et al., 2001). A typical example is found in Belnap's study of factors influencing the practice of three math TAs (Belnap, 2005). The following excerpt is his reflections of the three classes he observed when a TA, Lisa, taught:

> From the very beginning, Lisa's teaching style consisted of lecture, which she would begin shortly after giving a few announcements or reminders. Initially, this lecture incorporated a cycle of instruction, illustration, and assessment. First, she would provide definitions and explain ideas, then she would show various examples, and finally, she would lead the class through sample problems, quizzing them occasionally for an answer or for single steps in a problem (Belnap, 2005p. 50).

This characterization gives a general idea of the types of activities one might observe in Lisa's class. However, there are many details that could be included to give a better understanding of Lisa's teaching, including whether examples and questions are chosen in response to student ideas or how much reasoning needed to be provided for an answer to be considered correct.

5.2.1.3 TA behavior that appears similar can mask important differences in goals, motivations, and beliefs

Research by Speer (2001) provides a rare example of how examining TAs' beliefs about teaching can help researchers understand specific teaching behaviors. Her work suggests that typical assessments of instructor beliefs, especially surveys, are insufficient for understanding the individual instances of classroom practice. Speer studied two graduate mathematics TAs whose shared beliefs included: (1) the idea that learning mathematics requires complex problem solving in addition to practicing procedural skills like differentiating and (2) the idea that part of learning mathematics is learning about the relationships between ideas. However, the detailed case studies of the two students, Zachary and Karl, show important differences in their beliefs. A strength of this study is the fact that the primary data source was interviews in which the TAs discussed video clips from their classes, which allowed the researcher to better understand the TAs' explanations of their actions and motivations within the context of specific examples.

One example of a dissimilarity uncovered only through the video interviews is in the TAs' beliefs about questioning. Although both TAs thought that it was important to question students, Zachary felt that questions were necessary to check the strength of student understanding and to provide a mechanism for students to learn. Furthermore, when students were unable to answer his questions, he considered this evidence that they did not understand the concept. As a result, his questions were often motivated by his desire to understand the students' difficulties and to help them identify and overcome their problems themselves. On the other hand, Karl asked questions to model the behavior he wanted students to emulate when problem solving and to monitor their learning so he knew when to intervene. This second action was necessary because it was important to Karl that students not stray too far from the material that he had prepared and that all students complete the same problems. As a result of his corrections, students in Karl's class spent less time exploring why their original answers were incorrect than in Zachary's class. In addition, Karl often assumed that a student's lack of a correct answer was due to low confidence or a momentary "forgetting" of what they already knew. This meant that he had fewer chances to find the inadequacies in his students' conceptions.

These detailed case studies point out that surveys that ask about teachers' beliefs, even if they are specific, may miss potentially significant differences that motivate different teacher behavior. Further, observations of classroom work provide a way to see how these belief differences correspond to classroom teaching styles. By carefully examining Zachary's and Karl's teaching behaviors and correlating those behaviors with the TAs' reports of their intentions, Speer accounts for the different classroom environments that Zachary and Karl created.

Speer's analysis of Karl's beliefs is drawn from his own discussions of particular examples of his teaching, which allow us to better understand how he justifies his behavior. What is still lacking is examination of how Karl's students influence his interactions with him or how the context of the situation affects Karl's actions. An example is an analysis of an episode where Karl notices a student group's mistake and points to a portion of their solution, asking, "Does this work? Is this a solution?" One of the students, Greg, replies, "We want to say no," and laughs. Then a second student, Buddy, offers an incorrect answer to Karl's next question, followed by Greg offering a correct one.

> Since Karl assumed students understand when they state correct answers, there was no reason for him to ask Greg why it was that he wanted to say no. Since he did not necessarily attribute a lack of understanding to the students when they stated an incorrect answer, he was not necessarily compelled to follow-up on Buddy's error. (Speer, 2001, p. 182)

This analysis does explain how Karl responded to the students' statements, but it does not include an account of how those student responses influenced him. Instead, the explanation of Karl's behavior is primarily based in his consistent beliefs about how students learn and what counts as evidence that they understand.

We argue that the best way to understand TA classroom practice is to observe them while they are actually teaching and to analyze their interactions with students in detail, giving more than just broad-brushed generalizations about their teaching. Our analysis will show why such fine-grained analysis is necessary: TA behavior that appears similar can originate from different kinds of beliefs, which suggests the need for professional development that is responsive to individual TA differences.

5.2.2 Tutorials

The TAs we studied taught discussion sections for the introductory algebra-based physics course at the University of Maryland. As part of a comprehensive reform project (Redish & Hammer, 2009), the discussion sections, which had previously been traditional TA-led recitation sections, were replaced by tutorial sessions. In these sessions, students work in small groups on worksheets that emphasize conceptual understanding of physics. Each class has six tables at which groups of four students work together. Two TAs circulate through the room, working with various groups as needed.

5.2.2.1 Tutorial worksheets

The tutorials we use were developed at the University of Maryland and use the format established by the University of Washington Physics Education Group (McDermott & Shaffer, 2002). University of Maryland tutorials are designed to emphasize the reconciliation of everyday intuitive thinking with the formal science knowledge students are learning in the classroom. They also encourage students to explicitly consider and discuss their epistemological beliefs about learning physics (Elby, 2001). Each tutorial addresses one conceptual topic in the first semester of algebra-based introductory physics (Elby, et al.).

5.2.2.2 Tutorial preparation meetings

The TAs assigned to teach tutorials are required to attend a weekly one-hour preparation meeting. This meeting takes place in the same room where the TAs teach. TAs sit at the tables in groups of two to four people. The TA instructor usually leads a discussion of pedagogical issues arising from the previous week's tutorial. Following this discussion, the TAs work through the upcoming tutorial in their groups. In these meetings, the TA instructor attempts to convey the idea that the TAs' job is to facilitate learning by asking questions, rather than providing long explanations. These methods are explicitly discussed at the start of the semester, and the instructor models these behaviors while the TAs work through the tutorial as their students would. First-year TAs, in addition, attend approximately eight hours of instruction focusing on general teaching strategies, including classroom management and policies.

Our weekly tutorial meetings allow TAs to familiarize themselves with the tutorial they will be teaching and provide them with instructions about common student difficulties in each tutorial. These meetings are designed to accommodate the strengths and constraints TAs have: their limited time, advanced content knowledge, and minimal pedagogical content knowledge. However, our PD program fails to account for the ideas and experiences that TAs bring to their teaching, and we expect that most TA PD programs could be improved by considering these.

5.2.3 Theoretical Framework

5.2.3.1 Fine-grained understanding of TA practice can benefit professional development

Up to this point, the training that we have offered our TAs, like much of the PD offered to TAs in science departments nationally, has not been sufficiently research-based. Research on K-12 teacher professional development might provide a good starting point, since graduate students are typically novice instructors. However, graduate students are in some ways distinctly different from K-12 teachers. First, they usually identify themselves primarily as scientists and only secondarily (if that) as teachers, and thus see their primary job as research rather than instruction. Second, TAs often receive little if any pedagogical preparation: the Maryland program is typical in offering only the weekly one-hour tutorial preparation session described above, supplemented by intermittent seminars focusing on general teaching strategies,

In order to understand the kind of training TAs would most benefit from, we need to better understand the instructional environment in which they work. We need to identify the types of decisions TAs make as they teach, what sort of information they notice and use to make these decisions, and how they and their students negotiate what it means to learn physics through tutorials. Most importantly, we need to know why TAs make these decisions so that the professional development programs we create for them can be responsive to their current knowledge and beliefs about teaching. We seek to build this understanding by examining the minute-by-minute experiences of TAs as they teach.

5.2.3.2 Framing influences behavior

Our approach for this type of fine-grained analysis is based on *framing*, a concept developed by sociologists and linguists to study people's expectations about their activities and how these expectations influence their behavior (Bateson, 1972; Goffman, 1974; MacLachlan & Reid, 1994; Tannen, 1993b). The sociologist Goffman describes the study of framing as a search for answers to the question of "What is it that's going on here?" (Goffman, 1974, p. 8). Frames are what people use to make sense of the activities going on around them, and to help them decide what actions are appropriate in a given situation. Individuals are always framing what they are doing, albeit mostly unconsciously, and communicating that frame to their fellow participants. The process of framing is influenced by the expectations that the people involved in the activity bring with them. These expectations are built up from past experience and allow people to use their experiences to make sense of what is going on now.

To see how a person's framing affects his behavior, consider a father at his child's soccer game. He might frame his activity as rooting for a sports team or as nurturing children. How he frames the soccer game will lead him to notice different things: if he is rooting for a sports team, he may pay attention to who is scoring points, whereas if he is nurturing his child, he may note who is having fun. This would also affect his behavior, leading to more partisan cheering in comparison to general encouragement. This example also demonstrates the role of context in framing, because a league championship might be framed as a competition, while an unscored scrimmage is more likely framed as an opportunity for fun. Contextual cues can also cause a change in frames, such as when a father rooting for the team suddenly focuses on his child's wellbeing when she is injured.

When we analyze TAs' teaching, we use evidence such as how much people talk, the types of questions they ask, the conversational pace, their body positioning, gestures, and register (word choice, syntax, pitch, etc.), to infer how they are framing the situation. We look for additional support for these analyses from the ways TAs talk about their teaching in interviews. While we use TAs' statements to corroborate our ideas about how they frame, we are careful not to assume that these will necessarily match their actions. This is because the relationship between framing and beliefs is not directly causal, as the next section explains.

5.2.3.3 Beliefs support but do not determine framing

We use the term beliefs as a general phrase to describe the declarative knowledge that TAs have about teaching and learning. (For our purposes, "beliefs" are not technically distinct from knowledge or values; while we acknowledge distinctions that other researchers have made (Pajares, 1992; Schoenfeld, 1998), these shades of meaning are not critical to our argument.) We expect that in general, beliefs are context-dependent: the context can influence which beliefs are activated (implicit dependence) (Aguirre & Speer, 1999), and/or people may explicitly decide that certain beliefs are only true in particular circumstances (explicit dependence). People can hold contradictory beliefs that are nonetheless quite stable in particular contexts. For example, most people think lying is wrong, but complimenting someone's new hairstyle, regardless of its aesthetic appeal to you, is generally considered acceptable. Similarly, a TA could express a belief that tutorials are too easy for students, and yet also think that students cannot do them. Thus, when we claim that a TA's framing is supported by stable beliefs (as we do in the data presented below), we also know that he or she has other stable beliefs, which in a different context could lead to a different framing. (For example, we have discussed the plausible relationship between TAs' buy-in and their social and environmental context in another work (Goertzen, et al., 2009).) This concept of beliefs differs from much previous work on beliefs and knowledge, which views beliefs as active across many circumstances (Brickhouse, 1990; Cronin-Jones, 1991; King, et al., 2001). It also extends our own previous work, in which a "beliefs" approach was associated with a unitary cognitive theoretical framework and was contrasted with the context-dependence of frames (Hammer, et al., 2005b).

In our approach, stable beliefs play a supporting role in framing. In the above example of a soccer dad, a man who believes in the need to develop toughness in a competitive world would more likely frame a soccer game as a partisan event than a man who believes that strong children are products of unconditional love. The more stable the belief, the stronger its relationship is likely to be to the framing of any particular situation. Beliefs can only influence framing, though: they cannot determine it, because that would exclude the effect of context, such as the other participants' responses.

How a TA frames teaching is influenced both by his or her negotiations with students about what kind of activity they are all engaged in and by the stable beliefs that the TA has about teaching and learning. The TA may be guided by beliefs about what would be appropriate in this situation, but the students' responses then either support or undermine the TA's actions, so that together they construct a shared framing of the activity. (This is not to say that participants always have the same framing: mismatched framing is common, and can lead to humor, conflict, or "talking past each other," depending on whether the participants recognize that they are framing in different ways (Goffman, 1974)).

By using framing to analyze how TAs teach, we attend to the variability within an individual TA. TAs are not firmly categorized as possessing a certain type of belief corresponding to their teaching practice. Rather, the goal is to identify the different ways TAs can behave in the classroom, and the reasons that, for example, they might lecture in one instance and ask probing questions in another. Explanatory power is sought in instances across TAs, rather than within a single TA. We generate coherent explanations of individual episodes using framing, but we do not expect TAs to behave in a globally consistent way.

5.3 Data collection and analysis

5.3.1 Participants

During the fall semesters of 2006 and 2007, University of Maryland graduate students who were tutorial TAs for the introductory, algebra-based physics course (Physics 121) were invited to participate in our study. 15 of 21 TAs consented to be interviewed twice, at the start and end of the semester. Graduate students conducting physics education research were excluded from the study. Many of the TAs had their classes videorecorded. We selected classes to record based on scheduling convenience and not on the basis of the TAs' teaching or past experience. During 2006, we also recorded the weekly meetings in which TAs prepared to teach the following week's tutorial.

Most of the TAs who taught tutorials were first or second year graduate students whose primary purpose in teaching was to support themselves financially before joining a research group. The majority were in their early twenties. The research university they attend is in a suburban metropolitan area and has a large undergraduate and graduate physics program. The only women assigned to teach tutorials during the two semesters of this study were physics education graduate students, who were excluded from the study. Thus, all the TAs in the study are male. (This is not an unusual situation at UM, where women made up 12% of the physics graduate population in 2005 (Committee on the status of women in physics, 2005).) Almost half of the TAs who participated in the study were not native speakers of English; however, all but one communicated easily in English.

We chose a smaller group of TAs to study in greater detail. The five "focal TAs" were selected because they were articulate about their teaching during their interviews or during TA preparation sessions. We watched multiple episodes of the TAs interacting with their students, seeking to describe and explain the TAs' behavior.

The three TAs discussed in this paper, Alan, Julian, and Oscar, were focal TAs. They are demographically representative of the larger pool of TAs: they were all in their first or second year of graduate school and two were non-native English speakers. We consider the examples discussed here to be representative of the larger sample of their teaching that we observed, although we observed episodes that we would not characterize as "focusing on indicators." We did not see all TAs focusing on indicators while they were teaching; one notable exception was a TA who had previously taught high school physics.

During our data collection, we became aware that TA support (or "buy-in") for the tutorials that they were teaching varied. In a separate publication (Goertzen, et al., 2009), we characterized the buy-in of the fifteen TAs we studied and discussed how the context in which they worked appeared to influence their buy-in. The three TAs discussed here are among those that did not buy into many aspects of the tutorials.

5.3.2 Design

When developing a case study, we use video recordings of TAs' classes to gain information about specific teaching situations and interviews with the TAs to gain understanding of their beliefs and attitudes about tutorials. We watch video clips of TAs teaching and seek to provide plausible framings that might explain their classroom behavior. We then analyze interviews with those TAs, seeking statements that provide insight into why TAs might be framing situations in the ways we see, and cycle iteratively between classroom video and interviews to confirm or disconfirm our hypotheses. The two different data sets allow us to investigate relationships between the TAs' behaviors in individual interactions and their beliefs about teaching in tutorial classrooms.

This method of iteratively comparing our analysis of a TA's teaching practice and beliefs about that instruction contrasts with many studies of TAs and teachers, which attempt to first understand the instructor through data such as interviews or written assignments, and then (in some cases) to compare these assessments to actual behavior. In the next section, we discuss an example of TA behavior that provides explanatory power across examples of several TAs' teaching.

5.4 Results: Using framing to understand TAs' Focus on indicators

As physics graduate students teach tutorials, they can frame their activities in different ways. For example, they might frame their job as helping students to look for consistency in their answers, or as an opportunity to assess students' understandings of physics concepts. One way in which TAs seem to understand their job in the tutorial classroom is as a search for indicators that students have the appropriate knowledge. This focus on indicators is their understanding of the local activity, and is a nested subroutine situated in the way they more globally frame their jobs as TA instructors. The indicators they seek vary, but are all more superficial than detailed explanations – for example, key words, a particular type of reasoning, or correct answers.[8] TAs ask questions of and interact with students toward achieving their often-tacit goal of getting students to generate an indicator. When students have produced the relevant indicators, the TAs see this as evidence that the students have the necessary knowledge and the TAs' job in that moment is finished. In general, focusing on indicators results in TAs depending on evidence of understanding that physics education researchers would consider insufficient.

In these cases, the TAs in the episodes we discuss would not answer the question, "What is going on here?" by saying "I'm focusing on an indicator." Instead, their answer might be that they are "giving a hint" or "making sure the students understand." But among these explicitly-acknowledged ways of framing we see a set of behaviours that is locally consistent: the students provide feedback about their understanding that we might not consider convincing, but which the TA accepts as showing that the students

---

[8] It may be that "focusing on indicators," would be best considered as a subroutine of behaviors present in various ways TAs frame their teaching, rather than as a frame itself. For our purposes, attending to key words or numerical answers seems qualitatively different than attending to detailed explanations and that is the characteristic that distinguishes a "focusing on indicators" behavior.

understand. The students' responses develop positive feedback loops with the TA's beliefs and expectations to support the TA's focus on indicators, creating a relatively stable and coherent sense of the nature of the activity.

Although each TA described below can be characterized as "focusing on an indicator," there is behavior variation within individual TAs. For example, there is variability in the types of indicators (numerical answers, statements, etc.) that a particular TA uses as evidence of knowledge. This variability is to be expected: the context of the particular situation (which tutorial a TA is doing, the group of students with whom he is interacting, etc.) may encourage different behaviors within similarly framed activities. The consequences of such situational variability are seen in the first two examples, which both focus on a TA named Alan.

5.4.1 Alan focuses on indicators: correct answers

At the time of this episode, Alan was a first-year graduate student with experience in private tutoring, but no prior experience serving as an instructor for a class. In the episode below, Alan verifies students' answer to a tutorial question. In doing so, he uses a sketch that students have drawn as an indicator of the students' knowledge. Because he is focused on the answer, he fails to notice hints that not all of the students may be solid in their understanding, and thus that it may not be a good indicator of their knowledge.

In this episode, a group of four students are working on a problem, which presents a velocity time graph generated by a rolling ball. The tutorial asks the students to draw a track that would produce the motion in the graph (McDermott, Shaffer, & Rosenquist, 1996p. 688). Figure 3 shows the problem and a track that is a correct answer. Note that in this case, the shape of the track is almost a mirror image of the velocity graph.

In the following episode, the students have just drawn the track. As Alan walks by the table, S4 asks him to look at their solution. Alan looks at the track and then states that it is correct. He cautions the students that not all tracks will be the mirror image of the corresponding motion graph and ends by pointing out a small correction to S1's sketch.

B. Suppose a small ball rolling along a track produced the motion represented on the graph at right. What might the track have looked like? Sketch an arrangement of tracks you might set up to produce that motion.

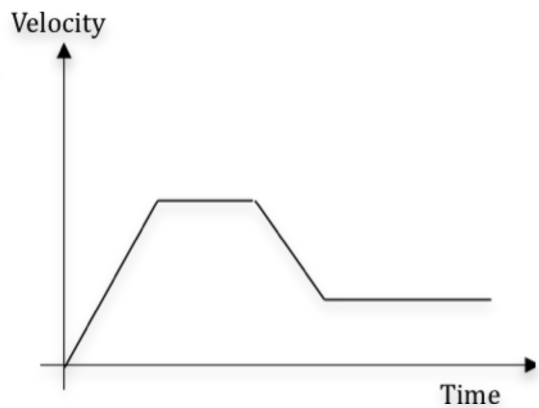


Figure 3. A tutorial problem showing a velocity time graph and the track that is the correct answer.

S4: How does this look to you?
[Alan looks at S4's paper]
S1: It's like the opposite of the…
Alan: Well, yeah, that's what it ends up looking like. I mean, I'm not sure that you can always say that it will be the exact opposite of… Maybe this one, in this case it happens to be.
S3: Okay.
Alan: But, I mean, I'm guessing you guys sort of thought this one through and sort of figured out-
S3: Yeah.
S4: Yeah.
Alan: -why it would look like that.
S4: Yeah, definitely.
S1: Uh-huh. Just that it rolls like down the hill-
Alan: Mm-hmm.

S1: -and straight-

Alan: Yeah.

S1: -then up the hill-

Alan: Mm-hmm.

S1: -and then flat again.

Alan: Right. Yeah. The one thing you want to be careful about, I, I actually know exactly what you meant, so this is right. But, like, you really want this one to be higher than this, because otherwise it won't get up.

S4: Yeah, I sort of, I changed it a little. I extended it.

Alan: I mean, as long as you realize that has to be true, don't worry about it too much. But…

S1: Mm-hmm.

S4: Yeah.

Alan: It's just conservation of energy. You guys haven't seen that in class yet.

Alan: The ball won't actually-

S1: Make it.

Alan: go further up than you had it in the first place.

S3: Yup.

[Alan leaves]

5.4.1.1 Alan's frame: Checking the students' answer

Alan would probably describe what he is doing in this episode as "checking the students' answer." After all, the interaction begins when S4 catches Alan's attention as he is walking by the table and asks him whether their solution is correct. S4 then shows Alan the picture of the track they have drawn, which presents Alan with an indicator of what the students are thinking. Alan does not have to rely on this picture to assess students understanding; he could ask for explanations or probe with question about similar situations. Instead, Alan tells them their answer is correct. He does not ask the students to explain their answer, and although S1 offers a description of the track's appearance, this does not tell Alan anything about how the students decided what the track would look like or how it corresponds to the graph they used to construct the track.

There are several pieces of evidence that Alan is not focusing on the substance of the students' ideas. As mentioned before, he does not ask for clarification. When listening to S1's description, he says "mm-hmm" and "yeah" repeatedly (lines 19, 21, and 23), and these affirmative sounds are spoken at almost the same time as her statements. This suggests that he is not listening closely, as his responses happen so quickly that there is little time for Alan to have thought about what S1 has said. His statements of "I'm guessing you guys sort of thought this one through," and "I actually know exactly what you meant" (lines 10-11 and 26-27) also show that he thinks he already correctly understands what the students are thinking.

When Alan says that he assumes the students have thought through the problem sufficiently, he may also be indicating that he expects that the students will tell him if they need help. His confidence in their ability to assess their own understanding and his belief that they mostly understand the material comes through in the way Alan corrects S1's drawing at the end of this episode. After looking at S1's drawing during her explanation, Alan cautions that she should be careful that one side of the track is higher than the other (lines 28-30). This is apparently different than what she has drawn, because she erases and redraws part of her picture immediately after he says that. The way that Alan phrases this correction, "I mean, as long as you realize that has to be true, don't worry about it too much," (lines 33-35) shows that he sees this error as a small matter, perhaps a detail that she forgot, rather than as a signal that she does not really understand the solution.

Alan frames this activity as checking the students' answer, and the ways the students interact with him support his framing. When Alan is talking, the students spend most of their time either looking at him or at the solution S1 has drawn and frequently say, "Yes," or "mm-hmm" (lines 36, 37, 44). These are signals that Alan may notice and interpret as evidence they are paying attention to the conversation. When he states his assumption that they have “thought this one through” (lines 10-12), they agree (lines 13-14) and do not ask further questions, suggesting that they are satisfied that their answer is correct. Moreover, S4’s initial question to Alan conveys what he wants to know from Alan, which is the correctness of their answer. Thus, the students also frame this activity as verifying their answer with the TA, and a shared, stable understanding of the activity is maintained.

The students drew a picture that is mostly correct, and they may in fact have a deep understanding of the velocity-time graphs. In this case, however, the available evidence of student thinking is not extensive, and Alan does not solicit more. His focus on indicators does not mean that Alan is incorrectly assessing student knowledge, but rather that the evidence he uses, the students’ drawing, is insufficient.

5.4.1.2 One of Alan’s beliefs: Instructors should give students the benefit of the doubt on conceptual questions

Alan’s use of a drawing as an indicator of student understanding is consistent with his beliefs about what good teaching looks like and how the tutorial fails to provide a good teaching environment. Specifically, he feels that failing to acknowledge and support students’ correct answers is bad teaching. He asserts in his interviews that the tutorial is unfair when it expects students to make mistakes, saying, “Basically, it assumes that… they were stupid… I’m seeing that every time I do the tutorial, there’s… at least one group every time who doesn’t make the stupid mistake. And then they feel, actually, kind of offended.” His personal experiences support this idea: “I remember being in high school and… my group goes through it [the assignment] quickly, and then it's very frustrating to be in a group where things went well, and the assumption behind everything the teacher is doing is that everybody will screw up." He thinks the tutorials are discouraging students when they assume the students will make errors, and he remembers feeling that way himself as a student. He reiterates that, "There are a lot [of tutorials] that ask questions in what I think… is a pedagogically dangerous way." Throughout his interviews, Alan's dedication to teaching and his desire to help his students is clear. He has convictions about the correct way to teach, and the tutorials contradict these.

One way to describe how Alan might justify what he is doing is that he is "giving students the benefit of the doubt." He sees some evidence that they understand the material, and it is important to him that teachers support students' correct answers rather than assuming that they are wrong. As a result, he offers a correction to the drawing rather than questioning the students about the incorrect part of it or probing for more details. The students may consider this correction minor, and are content to have their answers confirmed, so they do not ask for additional help. By giving students the benefit of the doubt, Alan does not have a chance to hear deeper reasoning that might challenge his assessment that they understand. Because both the students and Alan are satisfied with the encounter, no one challenges the assumptions anyone else is making, and a stable situation is established.

Alan's actions are also influenced by his belief that that tutorials were not that challenging for his students, explaining, "I thought the problems they were being asked to work on, they didn't really have that much trouble with… one could have raised the level of the problems they were asked to do." He suggested that his students struggled much more with problem solving than with the concepts in tutorials, saying, “I thought… when we were originally presented with this stuff that everybody would be struggling with this... That’s not happening… I’ve seen a lot of people who do already understand first of all, and second, I’m seeing massive confusion on what we would call traditional physics.” The problem the students are working on in this episode is conceptual, and Alan’s behavior in this episode is aligned with his belief that this kind of problem will not challenge his students and that they should not be exerting a great deal of effort on problems like this.

In this example, Alan focused on an indicator of student understanding – in particular, on the (mostly) correct answer a student had written on her worksheet. This indicator, while not without value, is not a reliable sign of student knowledge. Alan’s attention to this indicator is consistent with his belief that students who *might* have a good understanding should be given the benefit of the doubt. His values for tutorial teaching motivate his specific teaching actions. His selective attention to the indicator, along with reinforcement from the students, strengthens his conviction that the students probably understand the physics.

5.4.2 Alan focuses on indicators: Student affirmations

A focus on indicators can produce a variety of different behaviors, even for the same TA. A second example of Alan’s teaching illustrates this. In it, two students are working on a problem in the seventh tutorial (shown in Figure 4) in which they are asked to draw a free-body diagram of a block at the point when it has slid to the top of a loop-shaped track (Elby & Scherr, 2006). Alan determines that they cannot answer the question, and goes on to give them a hint. This time he focuses on students' affirmations to determine that they understand his hint.

II. Circular motion: the loop-the-loop

The re-greased block of mass 0.40 kg, released from rest from point C, slides down the track and around the loop-the-loop of radius R = 0.15 meters.

A. Draw a free-body diagram showing the forces acting on the block at point D, the top of the loop-

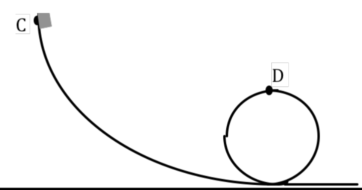
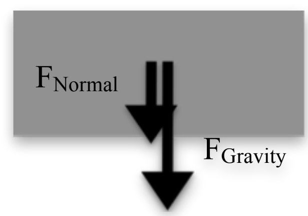


Figure 4. An excerpt from a tutorial on energy and one possible free-body diagram of the block at point D



In the following clip, the students call Alan over and explain that they do not know whether the normal force on the block from the track is pointing up or down. This situation is difficult for students because the correct answer is both unusual (this normal force is aligned with the gravitational force rather than opposing it) and counterintuitive (how does the block stay up if the only forces on it point down?). Before he can address their question, Alan is interrupted. When he returns to the table, he explains to the students that an object moving in a circle must experience a centripetal acceleration, which he labels "v squared over r." He indicates that this is a hint, not the answer to their question, but that it is information that they can use to help answer their question.

S2: I'm having intuitive problems with, with this concept.

Alan: Yeah, this is tough.

S2: With like, it seems so simple. ??? stuff. Well, there's gravity is pulling it down.

Alan: Right.

S2: And then there's, is there a normal force acting up? Or is that-

Alan: Yup.

S2: -acting down now.

Alan: Mmmm. Right, this is the hard thing. So, yeah, sure, there's a force of gravity down -

(Another TA interrupts. Alan leaves to talk to a different group and then comes back. The interruption lasts 1.5 minutes.)

Alan: Okay, getting back, yeah, so there's a force. If something is going to move in a circle.

S1: Yeah.

Alan: There needs, there's a force on it, it's the centripetal force. There's a centrifugal acceleration.

S2: Right.

Alan: So this acceleration is given, is because the velocity vector is changing direction. So there must be an acceleration on it.

S1: Right, right.

S2: Is that cause of kinetic energy, or?

Alan: It's related to kinetic energy. But, so, in the case of the roller coaster, the thing is going to move in a circle like this. There always needs to be an acceleration on it. Do you buy that?

S2: Yeah.

Alan: And that acceleration better not, ??? the centri- centrifugal acceleration.

S2: Right.

Alan: The one than goes like v squared over r. Do you guys remember that one?

S1: Yeah.

S2: Yeah, yeah, yeah.

Alan: So if that, if that is ever zero, it will stop moving in a circle. But you want it to keep moving in a circle.

S1: Right.

S2: Oh, that's ???

S1: Okay.

Alan: Try to use that and see how far you get with that. I mean, yell at me if it still makes no sense, okay? But that's sort of the observation. For something to move in a circle, which is what you want it to be doing, it better have v squared over r.

S2: Okay.

Alan: Sort of, um, that better not be zero.

S2: Or it'll fall.

Alan: It'll fall.

S2: Right.

S1: Okay.

Alan: I mean, it could be, it could be small. It can't be zero.

5.4.2.1 Alan's frame: Giving students a hint

Alan is again focused on indicators, but he has a different purpose in this episode than in the previous one. In this instance, Alan is looking for indicators that the students understand what he is explaining to them. This focus on indicators is a subroutine within his larger goal of giving the students a hint. The indicators the students provide include affirmations (such as "okay" and "right") and correctly stating a physical consequence if a certain force is zero.

At the start of the clip, the students call Alan over and S1 explains that he does not know how to do this problem. Alan's response is to provide the two students with information that he thinks will help them. When he explains that an object moving in a circle always experiences a centripetal acceleration, Alan considers this to be a reminder of knowledge they already know: he refers to it as the "v squared over r" acceleration and then asks, "Do you guys remember that one?" (lines 48-50). By focusing their attention on the acceleration, Alan may be expecting them to then connect this to the relationship of forces and accelerations represented in the formula $\sum \vec{F} = \vec{F}_{Gravitational} + \vec{F}_{Normal} = m\vec{a}$. While it is not exactly clear what Alan expects them to do next (or even if he has a particular path in mind), one way that the directions of individual forces can often be determined is by using the idea that the direction of the net force is the same as the direction of the acceleration. In any case, he is giving them information that he thinks they can use to determine the correct answer.

Alan's affect during this episode is friendly, conveying his desire to help. He speaks in a relaxed manner and makes eye contact with S2 often. While he is talking about circular motion, he frequently gestures, moving his hand in circular gestures that are expansive. He moves around often, which conveys a feeling of energy and perhaps restlessness. He reassures them that their trouble is reasonable, saying, “This is tough,” and “This is the hard thing” (lines 3, 12-13). His tone and body position support the idea that he is trying to assist the students by giving them a hint.

During his explanation, Alan seems to be looking for (and receiving) indicators that the students understand what he has told them. These indicators come in the form of affirmations: for example, they acknowledge that they remember the “v squared over r” acceleration (lines 51-52). Later, S2 correctly points out a physical consequence of zero acceleration on a loop-the-loop (line 67). Another indication that Alan is focusing on whether the students understand his explanation is his response to S2’s question, “Is that ‘cause of kinetic energy, or?” (line 36). (An object’s kinetic energy would not help you determine whether or not it has an acceleration.) Another TA might have viewed this question as evidence that the student thinks that the object’s kinetic energy causes the acceleration, whereas Alan seems to view it as a minor error that is easily dismissed. Alan’s failure to notice that S2’s question could signal deeper confusion is further evidence that Alan is framing this activity as giving a hint and paying attention only to whether the students understand his hint. Thus, once the students have provided enough indicators that they understand him, Alan ends the conversation.

5.4.2.2 One of Alan's beliefs: Instructors should help students grapple with traditional problems

In many instances of Alan's teaching that we have watched, he states the answer to the students. A typical example occurs when a group of students calls Alan to check their explanation of what kind of motion is represented on the position-time graph in Figure 5 (McDermott, et al., 1996p. 691). The students begin by correctly noting that the first part of the curved line could represent someone running forward who is at first getting faster. They then identify the straight part of the line (where the slope is constant) with " and then you're actually decelerating at a constant speed." Alan interrupts them, saying "Hold on, this is a position graph, so you're not decelerating, I mean you're just changing direction. You're coming back to where you started." The students agree, and then he continues, saying, "You pass zero, past your starting point… and then you stop." Alan often points out mistakes that students have made and corrects them. His action and tone convey the attitude that the students have just made a small error, and that he has confidence that they would have had the correct answer if they had avoided the minor mistake.

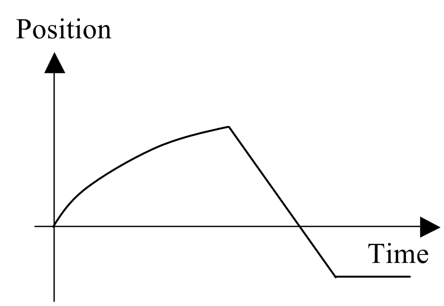


Figure 5. Excerpt of a tutorial on acceleration.

In the loop-the-loop episode, Alan's behaviour is more nuanced: he directly gives the students information at certain points but does not tell them the final answer. At the start of the conversation, Alan verifies that there is a force, although he is not definite about which direction it points (lines 11, 21-22, 25-26). He identifies this as the centripetal force, and associates it with the centrifugal acceleration (lines 26-27). He then explains the evidence that there is an acceleration (that the velocity is changing) and that it is the acceleration given by "v squared over r" (lines 30-32 and 45-46). This contrasts with the problem of actually determining which forces will be in the free body diagram, which Alan does not solve. There are several indications that he expects this question to be difficult for students: he remarks that this is "tough" (line 3) and "hard" (line 13) and he acknowledges that they may end up needing more assistance from him (lines 59-61).

Alan's decision as to whether to provide answers may be influenced by his opinions about whether the particular problem is difficult or not. In our analysis of the previous episode, we discussed Alan's belief that tutorials were too easy for his students. In that episode, Alan seemed to assume that the students understood the problem, which is aligned with his belief that conceptual problems are rarely difficult. In this episode, the students are working on a more typical quantitative physics problem, and Alan's assistance (rather than assumption of the correct answer) is aligned with his idea that students have difficulties with what he called "traditional physics."

Alan's specific instructional choices are also influenced by his beliefs about what students can do and how he should treat them, which are summed up by his desire to “give students the benefit of the doubt.” When students ask a question, Alan gives them the benefit of the doubt by assuming that they have worked to understand the problem and thus that they deserve an answer. If the issue is conceptual, he usually considers it appropriate to give them information directly. He focuses on affirmations such as “okay” and “right” as evidence that they understand, even though we might not consider these responses convincing. In the case of the free body diagram, however, Alan refrains from telling them the answer, perhaps because drawing free body diagrams is more closely aligned with his ideas about what students should be doing in a physics class and therefore he sees it as something they can productively struggle with.

The stability in this episode arises from the expectations of the TA and students, who may not frame the activity in precisely the same way, but who have expectations that at least do not contradict each other. Alan comes to the table believing that it is important for instructors to support students’ correct answers. This makes him likely to listen for indicators that the students understand what he is telling them. Students provide those indicators – in this case, verbal affirmations such as “yeah yeah.” While these may indicate understanding, they may also be signs of some other positive experience, such as receiving information that they expect will be helpful. Whatever the students’ intentions, Alan’s belief that the material is straightforward and his judgement that the students understand are not challenged. This sets up a locally coherent situation, which only ends when Alan is finished giving his hints.

Both this clip and the earlier clip are examples of Alan using indicators to determine when students have appropriate knowledge. His responses in the two instances, however, are motivated by two different pedagogical values. In this episode, rather than giving students the benefit of the doubt, Alan acts on his belief that students can and should productively struggle with more traditional physics problems. His instructional choices depend on whether the students indicate that they understand and whether Alan thinks it is a worthwhile and challenging question.

In both of the above episodes of Alan's teaching, Alan focuses on relatively superficial signs that students understand. In the first case the indicator is the correct answer and in the second case the indicators are student affirmations. In both cases, Alan's framing of the activity and his behaviors are supported by a set of beliefs: students find conceptual physics problems relatively easy; students have much greater difficulties with formal problems; and a teacher owes it to his students to give them the benefit of the doubt that they have struggled with a problem before calling him over. His specific instructional choices in the two episodes are different, which is probably due to the varying circumstances. In the first episode, Alan probably expects that students most likely already have a solid conceptual understanding, so he just needs to check their answer. In the second episode, the students are working on a more formal problem; this likely activates his belief that students have more trouble with (and a greater need to learn) traditional problem solving, so he supports this process without giving them the answer. In these two examples, we see that a TA with similar focus-on-indicator behaviors is motivated by different aspects of his underlying values for tutorial teaching in different episodes. In the following examples, we document other focus-on-indicator behaviors and the beliefs that accompany them.

5.4.3 Julian focuses on indicators: Instructionally targeted explanations

In the next example, a TA again seems to be focusing on indicators, but in this instance both the indicators and the way he helps the students fill them in are different. This episode takes place in the ninth tutorial, and the TA is Julian, a first year graduate student. His students are working on a problem (shown in Figure 6) that asks for an interpretation of a number (Adapted from section 10, McDermott, et al., 1996) .

Several tutorials have asked students to provide an interpretation of a calculated number, which is described as "a statement that tells you what the number means physically" (McDermott & Shaffer, 2002). In the following example, an acceptable interpretation of the number 2 would be "the number of grams in each cubic centimeter of stone." The tutorial is scaffolding the idea of portioning out the

> A certain stone has a mass of 120 g and a volume of 60 cm^3.
> **Consider the quantity 2 = 120/60.**
> *What is the name of the quantity in this context (if it has one)?*
>
> *What is the interpretation of the quantity in this context? (Recall that an interpretation often begins with "It is the number of…")*
>
> *Use the interpretation to find the mass of 7 cm^3 of the same kind of stone.*

Figure 6. Excerpt of a tutorial on the properties of matter.

grams to each cubic centimeter, or "package reasoning." Thus, to find the mass of 7 cm^3 of stone, one may imagine seven one-cubic-centimeter pieces of the stone; since each piece has two grams of stone, the mass of the $7cm^3$ piece is 14 grams.

An alternative means of determining the mass of the stone is to use the formula density = mass/volume. While this method is also correct, it can support routine application of an algorithm rather than a thoughtful conceptualization of the properties of matter. For this reason, the tutorial's focus is on helping students construct and use interpretations of calculated numbers rather than formulas (Arons, 1976).

The interaction below occurs after the students have called Julian over to ask a different question. Julian asks them how they used the interpretation of density. He suggests that their original answer uses the equation instead of their interpretation, and after verifying their interpretation he guides them in phrasing their answer so that it uses their interpretation in the way the tutorial expects. (Speech turns that overlap are bracketed by the symbols ⌈⌋.)

J: So, how did you use your interpretation for the density to determine how much mass the object has?

S3: Ah, you mult-, er, calculate the ratio of mass over, yeah, mass over volume, and multiply the volume by the, by the density and you get the-

J: I don't know if that really uses your interpretation. That sort of more uses an equation.

S3: Oh, okay.

J: So you know, so you're sort of saying you know density is this, so you're trying to find a mass that satisfies this density. But that's not really using your interpretation.

S3: Grams and centimeters, so…

J: So, how would you go about using your interpretation?

S3: Well, you need the number of grams, number of grams in seven centimeters and density's, I don't know. I'm not sure how to explain it without using the equation.

J: So what is your interpretation, first of all?

S3: Number of grams, uh, in a cubic centimeter.

S2: Stuff in an amount of area.

J: Okay, so there's two grams per cubic centimeter, is that what you're saying?

S3: Right, yeah.

J: So, I think it's more of a-

S3: Okay.

J: two is the number of grams per cubic in a cubic centimeter for an object.

S3: To get seven cubic centimeters, you have, there's two… two grams for every cubic centimeter.

S4: ⌈Sorry.⌋

J: ⌈Right.⌋So that would be a good way to think about it, ⌈except, well- ⌋

S5: ⌈Better be.⌋

J: -a good way ⌈to use your interpretations is that-⌋

S4: ⌈Not anymore.⌋

Julian: -is that so, for ever- you have seven cubic centimeters. And for every cubic centimeters you're going to have two grams. So you're going to have two, four - seven two-gram units. So, so that the total's fourteen grams.

[Julian leaves the table.]

5.4.3.1 Julian's frame: Guiding students to the instructionally targeted answer

In this episode, Julian is looking for what he takes to be the instructionally targeted answer, for both the interpretation itself and in the way the interpretation is used to solve a problem. There is evidence of this from the beginning, when he tells S3 that his answer does not use the interpretation as Julian expects (line 9-11, 16-17). The fact that Julian is focused on what the students are *not* doing is strong evidence that he is looking for something in particular.

When S3 seems unable to offer an answer Julian would find acceptable (lines 18, 21-25), he backs up and asks what their interpretation is. Here he also looks for the instructionally targeted explanation. S3's reply of "Number of grams in a cubic centimeter" (lines 28-29) is close to the ideal answer, because it is consistent with the idea of package reasoning (portioning out the grams to each cubic centimeter) that the tutorial developers want students to use. But Julian does not find this adequate, as signalled by the phrase "So, I think it's more of…" (line 35) followed by his offer of the correct answer in lines 37-39. This same pattern is repeated when S3 tries to use the interpretation by applying it to seven cubic centimeters of stone (lines 40-42): he appears to be very close to the correct answer, but Julian again signals a correction with "Except, well, a good way to use your interpretations is…" (lines 45, 47-48) followed by the answer.

Lastly, when he thinks that he cannot lead students to the right answer, he states the answer (lines 50-55) and then leaves the table. This indicates that Julian perceives his job at this moment to be done. The students have the right answer, although he had to present it to them. In a way, Julian has provided his own indicator.

Often when TAs focus on indicators, it leads them to be too generous with attributing understanding, as we saw in the examples with Alan. In this case, however, Julian has stricter criteria for a "good answer" than the tutorial developers desire. S3 demonstrates ideas that suggest he is making progress toward the right answer (lines 28-29 and 40-42) but they do not use the wording that Julian wants. S3's answer, "Number of grams in a cubic centimeter" is actually closer to the tutorials developers' targeted explanation than Julian's rephrasing of "per cubic centimeter"; including the word "per" often indicates a rote memorization of the density definition rather than a successful use of package reasoning, which was a point stressed in the TA training meeting the week before. Julian's attention is on the precise wording that he expects in the correct answer. He provides this precise wording twice, failing to notice that S3's answer is well aligned with the instructionally targeted answer.

The students in this episode might characterize what they are doing as "checking their answer" or see Julian as "helping them get the answer," a framing that does not conflict with how Julian has directed the conversation. For example, Julian asked about their interpretation, establishing the topic for the conversation, even though the students originally called Julian over. Likewise, S3 and S2 try to answer Julian's questions (lines 5-8, 21-25, 28-29, 30), thus indicating that they are willing to pursue the topic and direction established by Julian. In addition, S3 attempts to apply Julian's interpretation (lines 40-42), demonstrating that he is trying to make sense of what Julian said. Therefore, when Julian tries to nudge the students towards the answer he wants, the students cooperate and do not offer challenges, and a locally coherent situation is established.

5.4.3.2 One of Julian's beliefs: TAs should ensure that students have the right answer

The beliefs and attitudes Julian expresses in his interviews about the tutorials connect to his valuing the instructionally targeted explanation in this example. In his interviews, Julian frequently talks about the importance of students having the right answer when they are done with the tutorial and the idea that his job as a TA is to make sure they have that answer. He worries that the tutorial can harm students when it does not provide a way for them to check their answer, such as when "there's no, like direct answer and students get worried because like they're working together in a group… They may all come to the wrong conclusion and so like they have no way of knowing that their conclusion is wrong."

He thinks it is his job to help get students to the right answer, but that this has to be done carefully: "I think the best way is to start from where they're thinking and try to lead them to where you're thinking… Go step by step from their point of view to your point of view." Guiding the students in little stages is important because, "If I get them to think about it first and then talk to me about it, then they will have to stop and then try to realize what the question was rather than just hear the answer and then move on to something else." Julian's belief is well aligned with a constructivist philosophy; it goes awry here for the subtle reason that his view of what constitutes a good answer is narrow.

His behavior in the previous segment is consistent with his beliefs in the importance of the correct answer and student construction of that answer. If the students do not have the correct answer, then they need to learn it before he leaves the table. He attempts to elicit the correct answer from the students, an action that aligns with his belief that students should construct their own answers. When this fails, however, he tells the students the answer. In this moment, it may be that his belief that students need to have the right answer when they are done is more central than his belief that students should construct their own knowledge.

In the example discussed, Julian sees the correct answer as the version of the interpretation that was discussed in the TA preparation meeting. Interpretations are usually tricky for TAs to teach, because they require a particular articulation of reasoning that is unfamiliar to both students and TAs. In this case, Julian may not have considered any other ways students might demonstrate the instructionally targeted understanding other than the particular formulation that he developed during the TA meeting. Thus, Julian helps the students by leading them with his questions to the answer he thinks they need to have.

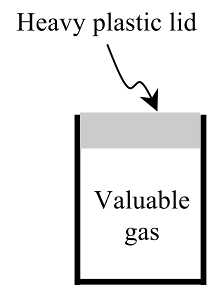
5.4.4 Oscar focuses on indicators: Answers to canonical questions

The final example comes from Oscar, a second year graduate student who was teaching tutorials for the third time during the semester we taped him. The conversation discussed below occurs approximately halfway through a tutorial in the eleventh week on ideal gases (Elby & Scherr, 2006). The students have completed the tutorial and are talking off-topic when Oscar notices that they are done and comes over. This is the first time a TA has talked to the group during the tutorial session, and Oscar uses it as an opportunity to review all their work. This episode shows the first two and half minutes, in which they discuss the content of the first page, which is part of a ten-minute discussion of the whole tutorial. The start of the worksheet, shown in Figure 7, presents a container filled with an ideal gas at a pressure of one atmosphere and held in by a heavy lid that is free to move up and down. The students are asked whether the lid will hold the gas in or whether it is “on the brink” of letting the gas out; the correct answer is that the combined forces of the lid and of the air above (also at one atmosphere) will definitely hold the air in.

Oscar begins this interaction by asking the students how much gas they could put in the container without holding the lid on, which is the last question on the page (question B, also shown in the figure). The expected answer is that you would need to know the weight of the lid, but that the maximum pressure would be greater than one atmosphere. The students answer with ‘one a.t.m.’ (atmosphere) and Oscar accepts this answer. Oscar has apparently forgotten that the lid has mass, because this is only true if the lid is massless. He then goes on to ask them how they could put more gas in, and continues to question them until they establish that the volume of the container would have to be increased to contain additional gas.

I. A valuable substance

Imagine a cylindrical container like the one shown at right, which is sealed with a heavy plastic lid. Instead of sitting on top of the container, the lid sits inside the container walls as shown, and is free to move up and down inside the cylinder with negligible friction. Inside the container is some amount of an ideal gas at room temperature.



Suppose the gas in the container is some valuable substance that we don't want to have leaking out. There is a lubricated seal around the inside of the lid designed so that no gas should enter or leave the container. However, if the pressure in the container is too high, the lid might fly off.

A. Suppose the gas in the container was at a pressure of 1.00 atm.

1. What's your intuition – would the lid stay on? Would it definitely seal in the gas, or would it definitely leak, or would it be just on the brink? Record your gut feeling here and discuss it with your partners.

[Several questions are omitted.]

B. What maximum pressure could the lid sustain without anyone holding it in place? What would you need to know about the apparatus in order to calculate a numerical value for the maximum pressure?

Figure 7. Excerpt from a tutorial on the ideal gas law.

Oscar: You guys are done?
S4: Yeah.
S1: Pretty much. Woo-hoo.
Oscar: All right. So, um, go back a page. Go back another page. What does that say?
S4: Oh, ??? first page.
Oscar: All right, well, okay. So you guys, you guys already have the benefit of knowing what's to come. So, what's the point of this here? Okay, what's the result? How much gas can you put in there without holding, um, holding the lid on?
S3: Uh, one a.t.m.
Oscar: Why?
S3: Cause there's one a.t.m. on the outside, so it balances out.
Oscar: How could you, uh, put more than one atmosphere in there?
S3: The lid would have to weigh more, I guess, the mass of the lid.
Oscar: That's one way.

S3: Temperature, also.

Oscar: What could you, what could you change about the, uh, about the, uh, container?

S3: Increase the volume?

Oscar: Right, and how could you do that?

S3: Uh, the height of it?

Oscar: Yeah.

S3: Increase the height of it?

Oscar: So if there are two, so if the sides of the cylinder went up a lot farther, there are two atmospheres in here, one atmosphere outside, what would happen?

S3: You could have more, it would allow for more, um, pressure inside.

Oscar: Right. So you have more, so what would happen? Does the lid move?

S1: Yeah.

Oscar: Why?

S1: Cause there's more pressure on the inside.

Oscar: Right. So how does it move? So it moves up a little bit and what happens?

S3: It stops and ???.

S1: Yeah.

Oscar: When does it stop?

S3: Um-

S1: When it equalizes.

S3: Yeah.

Oscar: Okay. And when is that?

S3: When-

Oscar: How much does the volume have to increase by?

S1: One at-, er.

S3: Uh.

S1: What does it have to increase by?

Oscar: Yeah. How much does the volume have to increase?

S3: Is it, is it inversely, as the pressure goes up?

Oscar: What is? PV=nRT.

S3: Yeah.

Oscar: You're given that formula, right. So if, so you have initially, uh, two atmospheres and one volume.

S1: Mm-hmm.

Oscar: So you want one volume-

S1: So it would be twice as much.

Oscar: Right. Twice as much. Okay. So, go on to the next page.

5.4.4.1 Oscar's frame: Steering students' canonical physics reasoning

In this episode Oscar asks questions about two different physical problems. The first conversational segment (lines 1-18) concerns a container of ideal gas with a moveable massless lid; the question he is asking is, "How much gas can you put in the container without holding the lid on?" The second conversational segment (lines 19-75) starts with the same physical set-up, but now the question is, "How can you alter the set-up so that the container will have a higher pressure?" We characterize these questions as “canonical” because they are questions commonly found in introductory physics textbooks.

The first conversational segment is puzzling because Oscar seems to be asking question B in the tutorial, but he accepts S3’s answer of ‘one a.t.m.’ as correct (lines 15-16). This implies that Oscar is picturing a container of ideal gas with a massless piston lid. (S3’s answer would be correct if the lid had no mass and the outside pressure was one atmosphere.) This is similar to, but not precisely the same as, question B with the heavy lid. Oscar may not have noticed this difference because idealizing a lid as massless is common in ideal gas questions. Oscar’s mischaracterization of the problem, which is probably unintentional, is evidence that he framing the situation as solving canonical physics problems.

The second conversational segment offers multiples pieces of evidence that Oscar is seeking a particular answer. For example, the students offer two potentially correct answers to his initial questions: if the mass of the lid was increased or the temperature of the gas was decreased more gas would fit inside the same volume. The students’ answers could lead in these directions (lines 21-22, 24) and both times Oscar indicates that those answers are not the ones he is looking for by prompting them for an additional answer (lines 23, 25-27). Next, Oscar indicates that he approves of some answers by affirming them and asking a new question that builds on the previous answer (lines 29-30, 41-43, 48-50, 57), with statements like “Right, and how could you do that?” (lines 29-30). Additional support for the idea that Oscar is seeking particular answers is that these are guiding questions, such as “Does the lid move?” (lines 42-43) and “When does it stop?” (line 53). These questions constrain the students’ responses because the required answers are brief words or phrases.

Oscar is using an answer with particular reasoning as an indicator of understanding in the second part of this episode. His guided questions help the students figure out which answer he would like to hear at each point, until they answer the original question, how more gas can be put in, with the particular answer of “the volume must be increased.” They then must apply this knowledge to the particular question of how much the volume would need to increase to contain twice as much gas (lines 70-75).

The tone and pace of Oscar’s conversation, along with his body positioning, provide clues to how he is framing this interaction. He speaks louder than any of the students and when he gives directions to turn the pages, his tone is commanding (lines 4-5). The majority of Oscar’s speech turns occur immediately after the previous student turn, sometimes even starting before the student is finished speaking, whereas there is a noticeable pause after his questions before a student speaks. This contributes to a feeling that Oscar is setting the pace for the conversation, and that this pace is faster than the students are going. There is no chance for the students to ask questions, unless they would ask a question in place of answering one of Oscar’s questions, because as soon as a student has finished speaking, Oscar poses another question. When he approaches the table, Oscar leans forward and firmly grips the sides of the table, as seen in Figure 8. He continues this during the entire episode, letting go only when he gestures. His hips sometimes rock from side to side, but his hands and feet generally remain firmly positioned. This posture corresponds to the way Oscar is framing. He is leading the conversation, steering the students to the correct answers, and tightly controlling the acceptable responses.

Figure 8. Oscar's posture during the conversation

The students' responses help sustain the way Oscar is framing this activity. The answers they give are short and do not introduce any information beyond what he has requested. Although it appears that they are not always certain which answer he would like, they keep offering answers until Oscar accepts one of them. They also do not introduce questions of their own which might change the direction of the conversation. (The only student question occurs at line 63, which is a paraphrase of Oscar's question.) The students cannot know what answer Oscar wants because they (and we) do not know what situation he is picturing. In fact, we can only figure out afterwards what Oscar is thinking about by considering what answers he accepts as correct. The fact that the students are willing to offer answers about a situation that they probably cannot make sense of is further evidence that they are allowing Oscar to direct the conversation.

Oscar's attention to answers of canonical questions is a locally coherent activity, which is a larger part of the guided questioning he uses to direct the conversation toward canonical physics reasoning. The focus on indicators appears as a simple loop, in which an unacceptable student answer leads to Oscar re-asking the question and an acceptable student answer (which is the indicator Oscar seeks) leads to the next loop. The students' behavior does not challenge this pattern, so it remains coherent during the episode.

Both of the physical situations that Oscar introduces during this episode are typical situations found in physics textbooks. Neither of the situations comes directly from the tutorial. The first is a modified version of the tutorial question B, and is noteworthy because Oscar does not indicate that he notices that he has modified the question. The second is more obviously a problem that he is introducing. The similarity in both of these sets of questions is that they focus on the relationship between variables in equations. That is, Oscar is thinking about the equation PV=nRT and directing the students' attention to how these different variables (and the quantities they represent) relate to one another. The next section discusses why we think Oscar focuses on these relations.

5.4.4.2 One of Oscar's beliefs: TAs need to get students going in the right direction

We have observed that Oscar often attends to the idea of how variables relate when talking to students. In one example (discussed in Chapter Four), a group of students are considering a situation in which a 2000 kg truck collides with a stationary 1000 kg car. They are told that the truck slows down by 5 m/s and then asked to figure out the new speed of the car. The students tell Oscar their answer is 10 m/s, which he confirms. They support their answer by the reasoning that the car's mass is half as much as the truck's, which we would consider an acceptable answer. Oscar asks for further reasoning, eventually using guided questioning to prompt them to say that the forces that each object experiences must be the same, and since the masses are different, the accelerations will also be different. During the discussion, Oscar declares, "The basic problem in pretty much every last physics question you'll ever answer is to figure out what's the same and what's different. Either before or after." This statement, along with his questions centered on the F= ma equation, show that Oscar is focusing on the relationships of variables in equations.

In his interviews, Oscar stressed the need for students to be given a context for the problems they are working on. He said, "Sometimes I felt… they really just need to be given the answer. If they're just given the answer, you know, they know what to work towards, and maybe that's the bigger picture they need. Seeing how one thing leads to another." He did not think that the tutorials did this on their own: "Sometimes, since they're [the students] left to their own devices, they can go off in different directions." He was concerned that students were given too much freedom to follow different lines of reasoning and thus would not learn the concepts they were supposed to learn. Oscar also expressed reservations about the usefulness of tutorials for his students; he disagreed with the tutorials' focus on qualitative understanding and connecting this to their common sense intuitions and felt that students would be better served by constructing meaning through using equations.

He also thought he had improved in his ability to ask questions that provide the needed context to students. Oscar chose to teach introductory courses for nonmajors repeatedly because he thought that his initial experience teaching tutorials had better prepared him to ask students questions that could help them. When he was explaining why he had volunteered to teach tutorials a second time, Oscar said, "I suppose at the beginning I think I did a lot more rephrasing their own question to me… Whereas now I think I'm much more capable of phrasing a question that still gives them some information and points them much better in the right direction." This statement shows that Oscar has deliberately chosen to disregard the instructions he received during tutorial preparation meetings to reflect the students' question back to them. His intentional decision to use strongly guided questions is not aligned with the tutorials' philosophy, but his reason for this choice is admirable: he thinks these questions help students more.

By asking students about canonical physics situations and expecting them to reason about the relationships of physical quantities, Oscar is providing a context for the new conceptual knowledge students are acquiring. This is something he considers an important part of learning physics, and something that he feels the tutorials are not accomplishing.

5.5 Implications for professional development

The identification of the pattern of "focusing on indicators" leads to the question of how TA professional development (PD) could better address this behavior. One seemingly plausible intervention would be to instruct TAs in the importance of completely eliciting and understanding student ideas. We argue, however, that this would be just as ineffective as our previous instruction to ask the students questions, if the beliefs underlying the behavior are not addressed.

Asking TAs to alter some of their beliefs about teaching and learning is asking them to make a significant change in how they think about an activity that they have participated in for over a dozen years. We suspect that the activities that we suggest would be effective primarily as part of a larger, sustained PD program. Such a program would likely need to include multiple opportunities for TAs to practice applying the ideas and methods they learn, as well as self-reflection and formative assessment about their teaching from their peers and TAs instructors. The goal of such PD would not simply be belief change, but a change in beliefs that is connected to changed classroom practice.

That said, we can imagine some activities that might be effective as part of the larger program we think is necessary for effective PD. To better understand how PD might focus on TAs' beliefs, consider the example of Alan. In the first episode that we presented, Alan's focus on indicators stemmed from his belief that instructors should give students the benefit of the doubt. An activity that addresses this belief might involve having TAs watch video of students discussing their answers. The TAs could be asked to describe the students' ideas and assess their correctness after a small portion of the episode is watched and again after the students have fully discussed their reasoning. Our experience is that most people, including TAs, readily recognize the richness of student ideas when given the opportunity to reflect on and discuss them. Such an activity would provide the TAs with an opportunity to experience how only seeing a small portion of a student's reasoning can prevent TAs from recognizing interesting or problematic ideas students might have. The insight would die on the vine, though, without multiple opportunities for the TAs to relate that experience directly to their own classroom practice.

5.6 Conclusion

Fine-grained analysis of TAs' teaching contributes to the effective design of professional development programs. In order to help TAs grow as instructors, we need to understand not just *what* decisions TAs make, but *why* they make them. The three TAs we discuss here all focus on indicators at one level, but are all doing different things at a finer-grained level. Furthermore, when we investigate the beliefs that underlie these behaviors, we find that they vary for each TA. Triangulating between these fine-grained behavioral observations and the beliefs that underlie the behaviors allows us to gain the deeper, more respectful understanding of TAs that is needed to inform their PD.

The recognition that TAs can focus on indicators provides an opportunity for professional development instructors to help TAs become aware of the strengths or weaknesses of various student knowledge assessments. This analysis shows that there are many ways TAs can frame their teaching that utilize the locally coherent "focus on indicators" behavior. Attending to these larger frames may help TAs become aware that focusing on indicators prevents them from attending to the substance of students' thinking.

Chapter 6 A new perspective: Respecting TAs' beliefs and experiences[9]

6.1 Introduction

Consider the following episode, in which four students are answering a question about the velocity - time graph shown in Figure 9. Their TA, Alan, overhears their conversation and steps in.

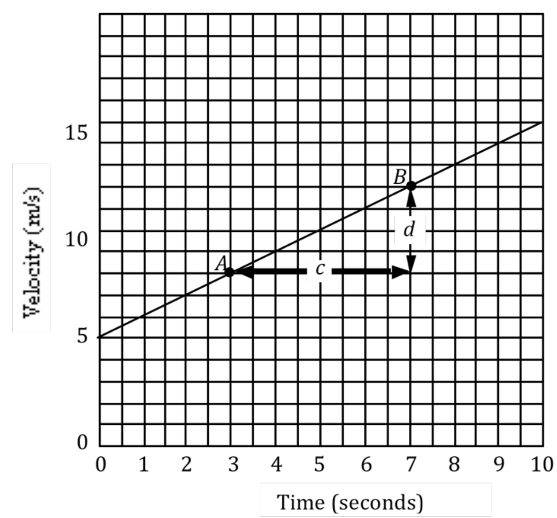


Figure 9. A velocity-time graph.

S2: [Reading] 'Give an interpretation of the ratio between c to d.' Isn't that just acceleration?
S1: Yeah.
S3: Well, the rate…
Alan: So that's the same thing I said, actually, when I was doing this.
S1: It was not.
Alan: They're trying to trick you, they're trying –
S2: Yeah?
Alan: They tricked me, I mean. Look very carefully at what they're asking you.
S3: C to d?
S1: Oh, it's just the ratio?
Alan: Well no, no, no, but acceleration would be this, d to c.
S3: D to c.
Alan: Because it's change in velocity over time.
S2: Oh, okay.
Alan: But here's its change in time over change in velocity. What the hell is that?
S2: I don't know.
S1: I have no idea. Good question.
Alan: Well, one incredibly legitimate way to say it would be, it's like the inverse of the acceleration. Whatever that is.
S1: Sounds good.

[9] This chapter has been submitted to Physical Review Special Topics - Physics Education Research.

Our first reaction upon examining Alan's teaching was to condemn it. As teaching assistant (TA) supervisors, we try to teach TAs to support student construction of ideas and to help students value the guided instruction offered by reform curricula such as tutorials. In this episode, we note that Alan prevents the students from discovering the meaning of the ratio c/d on their own. Furthermore, we are concerned about the way Alan dismisses the tutorial question. But when we examine this episode with more knowledge about Alan's experiences and beliefs, we find that his actions here are not ignorant, but rather informed by stable beliefs and expectations for teaching. In particular, Alan believes that his students rarely have problems with the conceptual parts of physics and that it is not fair to students when instructors or materials assume that students will get an answer wrong. Alan's teaching is well integrated with these beliefs, which are not, after all, entirely unreasonable. They are, however, inconsistent with the underlying assumptions of the professional development (PD) Alan was offered.

Effective physics instruction benefits from respecting the physics ideas that introductory students bring into the classroom. In what follows, we argue that it is similarly beneficial to respect the teaching ideas that novice physics instructors bring to their classrooms. We do not expect the *findings* about how to support student learning to apply to TAs: TAs differ from students in significant ways. For example, TAs probably expect to do less learning to be an instructor that a student expects to do in the classroom, their primary job in the classroom is framed not as learning, but as teaching. We do think it will be benificial if TA instructors apply the *attititude* toward TAs that we have found benificial with students, which is to respect (rather than ignore or disgarage) the ideas which students convey to the classroom. Learning about Alan's resources for teaching changed our thinking about what might constitute effective professional development for Alan and other TAs. We advocate a new perspective on TA professional development: one in which TAs' ideas about teaching are taken to be interesting, plausible, and potentially productive.

As we conceive it, a respectful approach to TA PD has two primary aspects: (1) treating TAs with courtesy and (2) looking for productive seeds in their beliefs and practices. By the first, we mean that TA instructors should treat TAs as partners in the endeavor of educating students – as thoughtful young professionals who care about doing their jobs well and whose decisions about teaching have a reasonable basis in their beliefs and past experiences. The second aspect is that TA instructors benefit from identifying productive resources and beliefs that TAs hold, in that they are a promising foundation for professional development experiences.

When we call for this kind of respect for TAs, we are not suggesting that TAs can do no wrong. TA instructors are likely to disagree with some decisions novice instructors make, and with good reason. The aim of respectful PD is to go beyond labeling the behavior as wrong and needing to be replaced, in order to understand what beliefs, ideas, and circumstances underlie that behavior. In this way, TA instructors can better understand how to encourage TAs to develop effective teaching practices.

6.2 Previous research on TA PD

6.2.1 There is only limited research that could inform TA PD

Graduate students have been partially responsible for physics undergraduate instruction for decades. The quality of the training provided to graduate TAs in all disciplines has been criticized for almost fifty years (Carroll, 1980), but there is little published research on what professional development is offered to graduate students who are TAs in physics or other science departments. Some TAs participate in workshops and seminars focused on classroom management, grading, facilitating discussion or learning questioning skills (Gilreath & Slater, 1994; Hollar, et al., 2000). These types of PD are often brief, and offered before TAs start teaching. Other TAs can take courses, often for credit, which span a semester or quarter. These courses are department- specific and offer instruction in pedagogical content knowledge and constructivist learning theories (Hammrich, 2001; Ishikawa, et al., 2001; Lawrenz, et al., 1992; McGivney-Burelle, et al., 2001). The effect of these courses is usually assessed by surveys or interviews. Such assessments may demonstrate changes in beliefs or conceptions, but because the TAs' classes are not regularly observed, there is no way to see how or if these courses affect TAs' teaching. Thus, while there has been a limited number of publications describing the various types of PD TAs may experience, it is difficult for TA instructors to know which programs should be used in their institutions to encourage more effective TA teaching.

6.2.2 Professional development offered to science TAs is rarely responsive or explicitly focused on treating TAs as partners

Since TA PD research has frequently assessed effectiveness through surveys, interviews, and written assignments administered at the end of the PD program (French & Russell, 2002; Hammrich, 1994; Ishikawa, et al., 2001; Lawrenz, et al., 1992; Price & Finkelstein, 2006), it is difficult to know whether the PD has been responsive. While it is possible that some PD instructors have modified the instruction they offered based on the ideas they hear from TAs during instruction, we can find no explicit discussion of how TAs' ideas influence what PD they are offered.

There is also little evidence to address the question of whether TAs are treated courteously (i.e. as partners in educating students), but informally we observe that TAs are often considered to be either blank slates or bearers of misconceptions. A work that exemplifies the type of courtesy that we are advocating is found Speer's study (2001) of the fine grained-differences of two mathematics TAs' belief and practices, in which the TA instructor works to develop a shared understanding of the TAs' beliefs and practices with each TA.

6.3 Data and methods

6.3.1 The larger project: Understanding and explaining graduate TA tutorial teaching

The data discussed in this paper was collected as part of a larger project that sought to characterize and explain the teaching practice of physics graduate students who were assigned to teach tutorials in introductory physics courses. During their discussion sections, the TAs taught using tutorials, which are worksheets that support students' conceptual understanding and encourage collaborative learning.

The students who take the introductory course using these tutorials at the University of Maryland are mostly majors in the health and life sciences. A significant portion are pre-med students. More than half are female, and there is wide ethnic diversity. The students are mainly juniors and seniors taking this course to fulfill a program requirement.

The TAs teaching the tutorials during the semesters we collected data were mostly first-year and second-year physics graduate students. All the TAs we observed were male. (Only one female TA was assigned to teach tutorials during the two semesters of observations, and she was eliminated from the study as she was also a physics education researcher.) Almost half of the TAs spoke English as a second language, but all except one communicated fluently in English.

During the fall semesters of 2006 and 2007, we asked all the TAs assigned to teach tutorials in the introductory course to participate in this study. Those who consented were interviewed at the beginning and end of the semester they taught. These interviews were audio taped and transcribed. We selected about a dozen classes to be regularly taped. This selection was based on researcher convenience rather than attributes of the TAs or students, although we only chose among classes taught by consenting TAs. We also videotaped two weekly PD meetings, one attended by all first-year graduate TAs for all courses, and one attended by all tutorial TAs.

6.3.2 Alan: A TA with well-articulated ideas about teaching

6.3.2.1 Choosing Alan

The particular TA selected for this case study, Alan, is a typical TA with respect to many of the demographic characteristics discussed above. He was a first year graduate student when he taught tutorials. He had no previous experience as an instructor of a class, but had tutored students in math and physics. He was a non-native speaker of English, but his English was excellent. He often participated in the discussions held in the weekly tutorial preparation meetings. He was unusually articulate in expressing his views about teaching and physics in both his interviews. It was important to him to convey his ideas about tutorials to the interviewer: he brought a tutorial book with him to his interview so that he could point out specific examples of instructional decisions in the tutorials with which he disagreed. We chose Alan as the subject of our case study because of his readiness to explain his ideas during interviews and meetings and because we found many patterns in his teaching that seemed connected to his views about teaching and learning. Alan is not unique in this respect; as we have discussed in other works (Goertzen, et al., 2009; Goertzen, Scherr, & Elby, 2010) we have generally found consistency between our TAs' beliefs about teaching and learning and their practice.

We taped Alan in two classes each week, one in which he was the lead TA and one in which he assisted the lead TA. Thus, we had a collection of 48 hours of his teaching, which was half of all the tutorials he taught that semester. Each class had two tables that were regularly taped by stationary cameras, so Alan was recorded for a small fraction of each hour, when he interacted with a recorded student group. Of the 48 hours we taped, we have watched and analyzed fourteen hours of his teaching, which is approximately 40 interactions. For this case study we selected episodes that we thought illustrated different aspects of Alan's classroom behaviors and were representative of his teaching overall.

6.3.2.2 Analyzing Alan

Alan was one of six "focal TAs," who we studied in greater detail than most of the UM TAs who participated in this project. We generally watched about five or six hours of teaching for each focal TA. We continued to watch episodes of the TA until we had built up an extensive understanding of the TA's practice.

When characterizing Alan's teaching, we did not try to fit his work into predetermined categories. Instead, we watched multiple episodes of his interactions with students on video, seeking to describe and generate plausible explanations for his actions. We continued to watch episodes until we reached saturation, at which point we could explain new observed behavior by what we had already learned about Alan from his interviews and previous video observations (Lindlof & Taylor, 2002).

We used the data from Alan's two interviews to generate our descriptions of his beliefs. When we refer to Alan's *beliefs*, we use the term to refer to his declarative knowledge about teaching and learning in the context of introductory physics. While others have carefully distinguished beliefs from goals and knowledge, these distinctions are not critical for our argument.

To create descriptions of Alan's beliefs, we read through the transcripts of the interviews and identified excerpts that seemed to reflect Alan's beliefs about teaching and learning physics. These statements were often about his own role as an instructor, the strengths and weaknesses of the tutorials, and what his students "should" be doing. We organized these statements into larger categories that we termed beliefs. For example, Alan's desire for his students to spend more time on quantitative problem solving and his statement that physics provides "extremely powerful machinery" to calculate precise results are both evidence of his belief that quantitative calculations are an integral part of physics.

Identifying Alan's beliefs from his interview data and generating plausible explanations for his practice occurred in tandem. We then used both of these analyses to create narratives of how Alan framed individual activities and how his beliefs supported these framings.

6.3.3 The professional development that Alan experienced

Alan was expected to attend three different types of professional development during the semester we observed him. Physics education researchers ran all three of these programs. The first was part of a three-day orientation offered to all incoming first-year graduate students in the physics department. The portion devoted to teaching preparation lasted about six hours. The orientation introduced the idea of physics education as a scholarly activity, emphasized that learning occurs when students construct their own knowledge, and gave them practical advice about grading and classroom management. The second was a weekly preparation meeting attended by all tutorial TAs. During this hour, TAs would spend about half the time discussing issues that had arisen in the previous week's classes and half the time working through the tutorial for the upcoming week.

Alan also attended ten weekly teaching seminars that all first-year graduate student instructors were required to attend. These no-credit seminars addressed topics of interest to TAs teaching tutorials, traditional discussion sections, and laboratories. Our discussion of Alan's professional development focuses only on the tutorial preparation meeting, because Alan's comments about PD were always about those meetings. This is likely because the one-time orientation workshop and the seminar for all TAs addressed general topics that are not as directly applicable to tutorial teaching.

The weekly tutorial preparation was originally intended to be an hour in which TAs worked on the upcoming tutorial in small groups, as their students would, while the TA supervisor modeled the questioning TAs would be expected to do when teaching. This is the model used at other universities that use the tutorials developed by the University of Washington Physics Education Group. The tutorial supervisor during the year Alan taught was one of the authors (Scherr). Noting that this group of TAs often grew restless after working on the tutorial for half an hour, she modified the weekly schedule so that the TAs spent the first half hour discussing issues from the previous week's teaching and the second half hour working through the tutorial. This allowed for a guided discussion of issues that were important to TAs (because they raised most of the ideas themselves), such as specific student difficulties the TAs noticed or what they thought students should be learning in tutorials. TAs worked through the same amount of the tutorial as they did without this discussion, and spent a similar amount of effort learning questions they could ask and common problems students have.

6.4 Analytic framework

6.4.1 Resources

People do what they do at least partly because it has worked for them in the past. Teachers teach in a traditional manner often because it is the way that they have experienced instruction, and, in the case of physics graduate students, it is a system in which most of them have excelled. Many TAs have learned physics in an environment where lecture and extensive homework sets of quantitative problems were considered the norm. Because these behaviors and experiences have proved sufficiently successful for TAs in the past, it is unreasonable to expect TAs to simply discard them when TA instructors present alternative teaching methods.

We take a theoretical position of respecting naïve ideas. The physics education community has done so regarding people's physics ideas, with the benefit that we can help students identify ideas that can be the basis for effective constructivist instruction (Hammer & Elby, 2003) and where they will need to reconcile these ideas with formal physics concepts. The same theoretical framework applies when the "students" are novice teachers; now the naïve ideas can be a basis for effective professional development.

These positions are supported by a resource-based framework, in which learners (whether they are students or beginning teachers) have a variety of ideas that are activated in different situations. People use these activated resources to construct knowledge and guide their behavior. These ideas are not categorically wrong or right, but rather are appropriate or inappropriate for the particular situation (Hammer, et al., 2005b). Such a framework provides an explanation for how novices can become experts: they begin to use resources from other contexts, adding new ones, and build up a more coherent structure of ideas (Smith III, et al., 1993). Smith et al. characterized such a framework as one that "emphasizes knowledge refinement and reorganization, rather than replacement, as primary metaphors for learning."(1993, p. 116) When this idea is applied to TAs, it means that we should assume that their problematic teaching practices are inappropriate to the situation, rather than wrong, and that as TA instructors we either need to help them build on the productive ideas they do have or help them activate beliefs and resources more appropriate to the situation (Hammer, et al., 2005b). For example, TAs have discussions with colleagues in which the answer is not known by one of the participants, and they can use this experience to encourage similar conversations among their students. Another productive belief would be the common graduate student understanding that struggling through an idea results in more learning than being told the answer, which most graduate students have experienced when doing their homework.

diSessa warns teachers about judging the "goodness" of student ideas (his remarks are specifically aimed at evaluating representations) because we can miss useful ideas that students have when they do not align with ours (diSessa, 2004). We are advocating a similar perspective on TA ideas, in which instructors respect TA ideas by viewing them as interesting, plausible, and worthy of understanding, with the intent of identifying productive starting points upon which to build responsive professional development.

6.4.2 Epistemic framing

In addition to providing an explanation for how Alan thinks about his teaching, our framework also needs to account for why Alan does what he does. When we considered the examples in the introduction of Alan explaining the ratio c to d, we saw that Alan dismissed the tutorial question and explained his answer to the question to the students. We assume that Alan, like most people, does not behave arbitrarily. Instead, there are reasons why he does these things, and why his students respond by quickly accepting his answer. One way to account for individuals' behavior is by examining their expectations.

Framing is a way of explaining how an individual or group makes sense of the activities they are engaged in (Bateson, 1972; Goffman, 1974; Tannen, 1993a). As people decide (usually subconsciously), "What is it that's going on here?" (Goffman, 1974p. 8), they draw on their past experiences to decide what behavior is appropriate. When a person receives a compliment, they can frame it as either being admiring or patronizing. A game can be framed as a way to have fun or a chance to show who is a better chess player. A TA who thinks it is important to build on student's ideas may frame a discussion as "understanding a student's idea of momentum"; the same discussion could also be framed as "checking a student's answer" if the TA was helping students prepare for an upcoming exam. We refer to these instances of framing as *episetemological framing*, because they involve decisions about how knowledge will be built in the particular situation (Redish, 2003). In the last case, we can see that although framing is actively negotiated moment to moment, it can be supported by potentially stable epistemological views and expectations for teaching.

This stability manifests itself as locally coherent sets of resources and beliefs, rather than as a set of beliefs that are uniformly activated in all contexts.

A group's framing of an interaction stabilizes when the individual ways of framing reinforce each other. As people interact with each other, their past experiences influence their expectations and this affects their behavior. Because framing takes place continually, the behavior of others then becomes further information that individuals can use to check whether they are framing in the same way as the group. We see, when examining episodes of Alan's teaching, that Alan often frames *assisting students* as *giving them information.* His students expect help, and consider TA-led explanations as appropriate in discussion sections. They listen attentively, ask questions to clarify what he is saying, and direct their attention to him; these actions all reinforce Alan's idea that unambiguously answering their question is the right thing to be doing.

We identify framings by examining verbal and nonverbal interactions, including linguistic signals and body language. Examples of evidence we use include what people say, along with such things as pauses, laughter, and body positioning. As we consider possible ways TAs are framing their teaching, we look for support for these framings from the interviews where they discuss their tutorial teaching. We do not assume, however, that TAs will behave in ways consistent with the beliefs they espouse during their interviews.

Framing influences our analysis at two distinct points. We need it to explain why Alan does what he does in the classroom, because his expectations about what he is doing, along with those of his students, help us understand pedagogical choices.

Framing also informs our analysis as TA instructors: we framed our activity differently at the start and end of our analysis. That is, when we began analyzing Alan's teaching, our unspoken answer to the question "What is it that we're doing here?" was "We are looking for places where Alan's teaching needs to be improved." This led us to concentrate on what Alan was doing wrong. When we reframed our analysis, the answer to the framing question became, "We want to understand why Alan does what he does." In contrast to the previous answer, this way of framing our activity focuses our attention on why Alan's teaching practice is reasonable to him. Thus, our reframing of our analysis caused us to shift our attention from Alan's teaching to Alan himself.

6.5 Contrasting our initial analysis with a respectful analysis of one TA's teaching

6.5.1 Critique of Alan: Interpreting Alan's actions in terms of our values and beliefs

In this section we discuss how our view of Alan changed as we learned more about his beliefs and could interpret his teaching through a more respectful lens. First, we present two episodes of Alan teaching tutorials and our early interpretations of his teaching, when we primarily focused on the ways his teaching failed to meet our expectations. We then describe Alan's beliefs about physics and how it should be taught to his students, drawing on his interview data. Lastly, we reexamine the tutorial episodes to show how a respectful interpretation can help us better make sense of his teaching decisions. Section 6.6 discusses how information we glean from interpreting Alan respectfully could be used to improve the PD we offered him.

6.5.1.1 Episode 1: Alan constrains the conversation and fails to elicit student ideas

This episode occurred during the third tutorial of the year, which helps students reconcile the idea that two colliding objects each feel the same force (Newton's Third Law) with the "common sense" idea that a larger truck causes more damage to a smaller car when they collide. The tutorial begins by asking students to use their common sense to generate a guess about which vehicle experiences a greater force during a collision. After doing so, they apply Newton's Third law to the situation and observe two carts colliding as a demonstration of Newton's Third Law. The tutorial then poses the questions excerpted in Figure 10. A correct answer to part A would be that the car gains 10 m/s because it weighs half as much as the truck and so it will react twice as much. In part B, the students are asked to calculate the truck's acceleration, which is also 10m/s by the calculation $a = \frac{\Delta v}{\Delta t} = \frac{5\, m/s}{.5 s} = 10\, m/s^2$.

The interaction begins when Student 3 raises her hand and Alan approaches the table. Student 3 tells him that they do not know how to calculate the truck's

> A. We'll start with a new question. Suppose the truck's mass is 2000 kg while the car's mass is 1000 kg, and suppose the truck slows down by 5 m/s during the collision. Intuitively, how much speed does the car gain during the collision? (Apply the intuition that the car reacts more during the collision, keeping in mind that the truck is twice as heavy.) Explain your intuitive reasoning.
> B. Does your answer to part A agree with Newton's third law? To find out, we'll lead you through some quick calculations.
> 1. Suppose the car and truck remain in contact for 0.50 seconds before bouncing off each other. Calculate:
> i. the truck's acceleration during the collision.
> ii. the car's acceleration during the collision (assuming your guess about its change in speed is correct).

Figure 10. An excerpt of the tutorial on Newton's third law.

acceleration. Alan asks them what the definition of acceleration is and then what the change in acceleration and change in time are. The students calculate the acceleration and Alan suggests that they can use the same method for the next part of the problem.

Alan: Hi, what's going on?

S3: Um, what's the, what happens to the truck's acceleration during the collision?

Alan: Okay, so you want to compute this acceleration during the collision, right?

S3: Right.

Alan: So, what is the definition for acceleration? If you don't know anything, just try using the definition. What's the definition of acceleration?

S4: [muttered] ???over time

S3: Distance…

S2: [muttered] Over feet time squared

S3: The change in velocity over time.

Alan: Right. So its change in velocity divided by the change in time. Or the time that it took for the velocity to change. So in this case, do you guys know from other things they've said, how much the truck's velocity changed?

S2: Yeah, five-

S1: Is that five…

S3: Five meters-

Alan: Five meters per second. Right, so it changed five meters per second. And how long did it take for it to change?

S3: A second. Sss.

S2: Half a second.

S3: Point five.

Alan: Half a second, right? So now you know the change in velocity and the change in time. You can get the acceleration from … Right?

S2: Like I said-

S3: So its-

S1: Ten.

S3: Ten. Is that a ten?

Alan: Yup. Five divided by a half is ten.

S3: Ten, ten meters-

Alan: Ten meters per second squared is the acceleration. Do you see how I arrived at that?

S1: Yeah.

S2: Yeah.

S4: Take five meters and divide it by the time.

Alan: Okay, the next thing you can also do using the same idea.

S?: All right.

When we first watched this episode, our attention was on the decisions that Alan made that we disagreed with. For example, the questions he asks constrain the conversation, so that the students have fewer opportunities to bring up problems that they may have noticed. Each student participates in the conversation to varying degrees, but Alan's conversational turns are the longest. Alan's gaze is usually on one of the students, but their gazes are mostly on Alan or the papers on their table, not on each other. Thus, the conversation is not one in which they are paying a lot of attention to each other's ideas.

Alan also fails to elicit students' ideas in this episode, even though the importance of building on students' ideas is one of the main ideas underlying the tutorial. When S2 asks her question (lines 2-4), he uses that question to diagnose what their problem is and he does not ask anything else to check if his assessment is correct. He also does not seek student ideas that he could build on: he does not ask what the students have already tried, whether there is some part they do understand, or whether the other students in the group could answer S2's question for her.

Alan makes additional assumptions when determining whether the students understand what he is doing. After his explanation, he asks if they understand how he calculated the acceleration (lines 47-48) and leaves soon after they say yes. The students may follow what he did, but Alan does not have a lot of evidence of the depth of that understanding, because he guided each step of the conversation and allowed few opportunities for students to make mistakes or discuss their thinking.

6.5.1.2 Episode 2: Alan directs the conversation and neglects student ideas

The fourth tutorial Alan taught helped students reconcile the commonsense idea that a net force is needed keep an object moving with the idea (from Newton's second law) that a force is only needed to change an object's velocity. The tutorial considers a child on a rope being reeled up at a constant speed from a well into which he has fallen. The students are led to see that their commonsense idea conflicts with Newton's second law and they then consider what would happen if the upward force of the rope was less than the child's weight. The scenario and the question the students are working on are shown in Figure 11 below. A correct answer to question 5 is that, if the rope force "compromises" between being less than the child's weight (which had made the child slow down) and being greater than the child's weight (which had made him speed up), then the child will move at a constant speed.

I. "Timmy's fallen down the well!"

To rescue a child who has fallen down a well, rescue workers fasten him to a rope, the other end of which is then reeled in by a machine. The rope pulls the child straight upward at a steady speed. The child weighs 250 N, which means gravity pulls him downward with 250 N of force.

[Two pages of the tutorial are omitted.]

5. It makes sense that, if the rope force remains greater than the gravitational force, the child keeps speeding up; and if the rope force becomes less than the gravitational force, the child slows down. By this line of intuitive reasoning, what happens to the child's motion if the rope force *equals* the child's weight, *i.e.,* if the rope force "compromises" between being greater than and being less than the child's weight? Explain.

6. Does Newton's second law agree with your answer?

Figure 11. Two excerpts of the tutorial on Newton's second law.

In the episode examined here, a group of four students is discussing question 5. As Alan approaches, S1 calls him over and asks him whether a child who is not accelerating would experience no force and no movement. Alan discusses the forces and accelerations of an object in a series of examples: first, a stationary object that has equal forces, which does not move; then an object feeling an upward force greater than gravity, which would accelerate; and finally one which is being pushed up with the same amount of force as gravity, which would not accelerate. Alan points out that in the final situation, the object will move at a constant speed. He concludes by telling them that movement does not imply acceleration.

S4: There would just be no change in velocity.

S3: Alan.

[Alan approaches table]

S1: No, but if… if the rope force equals the child's weight.

S4: That's what we were ask, this is the same question as here.

Alan: Hmmm? Yeah, okay, go, so ask your question.

S4: So net force is zero.

S1: So, there's no acceleration? And there, does that mean there's no force too? So does the child stay still?

S4: There's no net force. But-

Alan: Well-

S4: Like-

Alan: ???

S2: It doesn't stay still, it moves at a constant velocity.

S1: It's still moving?

S4: But it could be either, like if it were, if it wasn't moving, if the kid wasn't moving, and this equaled this, then he still wouldn't move. Like, it just means that there's no change in velocity. Sorry, go ahead.

Alan: So, no, no. Okay, so, so if um, how shall I put this? Suppose something is sitting still. Suppose I try to push, pull up on it, push up on it. With a force, with a force that's less than is holding it down. The force of gravity.

S1: It wouldn't go anywhere.

Alan: It wouldn't go anywhere, right? Suppose I push up with exactly the same force, it still wouldn't go anywhere.

S1: Yeah.

Alan: The force on it is zero, its acceleration is zero, it's not moving, right?

S1: Okay.

Alan: However, suppose I push up on it with just a bit more force than necessary to lift it. Just a bit more force than the force of gravity. It's going to accelerate.

S1: Uh-huh.

Alan: And then suppose I get lazy and I start pushing only as hard as gravity's pulling it down.

S3: ???

Alan: So, I got it moving. Its acceleration changed from zero to say one meter per second.

S1: Mm-hmm.

Alan: In a, in over a second.

S1: Uh-huh.

Alan: And then I only started pushing just as hard as gravity is pulling it down. At this point it's not going to accelerate any more. Which means that it's going to keep moving with the speed it had before I stopped accelerating it.

S1: Okay.

Alan: So, does that make sense?

S1: Yeah.

Alan: That’s what’s going on.

S1: So it’s still moving but there’s no accel-

Alan: But there’s no acceleration-

S1: No acceleration.

Alan: - just because something’s moving doesn’t mean that there’s acceleration.

S2: That’s what I said.

Alan: Only, it’s only if something’s acceleration that there has to be an acceleration.

S1: [quietly] Yeah. [louder]Okay. Thank you.

6.5.1.2.1 Alan focuses exclusively on answering S1’s question

This episode begins when S1 calls Alan over, in the middle of a discussion that the group is having about whether the child can be moving if the net force on him is zero. Alan asks what her question is and then he works on answering the question she has asked. In doing this, he ignores the other students’ ideas. One example of this occurs at the start of the episode. When S1 calls Alan over, he immediately approaches and leans over the table to read their papers. After S1 asks her question, Alan straightens up and steps back, directing his gaze at them rather than at the paper (line 16). At this point he is interrupted, and he continues to stand about a foot away from the table. When S4 indicates that she is done speaking (line 27), he steps closer to the table, and stands in front of S1. During S4’s explanation, Alan has separated himself both physically and mentally from the conversation; he has stepped away and he does not respond to any of the statements between the interruption and when he speaks again. Alan has interpreted his job during the encounter as answering a question, so he spends the rest of the time answering it.

In the previous example, we noted that Alan failed to elicit student ideas, but his misstep here is greater, because he is ignoring ideas that the students have voiced. In this case, S4 discusses her idea that no force just means no change in velocity (lines 22-27), which is correct, and could be expanded to include the idea that if the child were already moving he would stay moving. In addition, S2 asserts that the child is moving at a constant velocity (line 19-20). Alan does not seem to notice either of these potentially useful ideas. At the end, S2 notes that her idea was the same as Alan's when she says, "That's what I said" (line 79).

Alan directs this conversation by providing a series of examples to demonstrate the steps in his reasoning. His final conclusion is the answer to S1's initial question "Does that [no acceleration] mean there's no force too?" The fact that Alan is guiding the conversation comes through in the length and type of conversational turns. After Alan enters the conversation, all of the student responses are one line, or even one word (until Alan has made his point, which S1 reiterates in lines 72-73). He introduces all the examples, and receives a confirmation after each one. The students support his framing of this activity as answering S1's question: S1 affirms that she follows each step, and S2 and S4 remain quiet, sometimes looking at Alan and sometimes looking away, which is consistent with the group's shared understanding that Alan's explanation is aimed mainly at S1. Once Alan starts to speak, no student introduces an idea or asks a question, even to clarify.

When Alan directs the conversation so strongly, it prevents him from doing things we would like him to be doing. Alan does not provide an opportunity for the students to give him feedback about whether he has correctly identified their difficulty. He does not model the practice of building on others' ideas. There is also no chance for the students to demonstrate whether they understand the idea by applying it. Alan is conveying, through his actions, that tutorial is a time when students can get help answering questions. We, in contrast, want the students (and Alan) to see the tutorial as a time when students construct knowledge together.

6.5.1.2.2 Alan misjudges students' skill level

Alan's actions also convey a different understanding of his role than what we, as tutorial instructors, would prefer. We want TAs to see their job in tutorial as that of a guide: this will require the TAs to figure out what ideas the students have, where those ideas fail them, and to help them make the connections between their current thinking and the physics concepts. Instead, Alan's actions seem to be based on the assumption that the students will understand the information he gives them. When Alan explains and expects the students to make sense of it on their own, he is crediting them with more skills than they likely have. Alan knows that his students are not experts, so he adjusts his presentation of conceptual information to a simpler level than he would use with, say, his peers. But his actions are not tailored for an audience that may not share expert values like seeking coherence or skills such as seeing the relationship of concepts in an equation. Furthermore, when he treats them as equals, he is not acknowledging the difference in authority: unlike his peers, Alan's students are less likely to interrupt or disagree with him.

6.5.2 Alan's values and beliefs about tutorials

We began to consider Alan a thoughtful instructor when we understood his ideas about teaching and learning. This section explains some of his beliefs which we think most influenced his teaching in the clips we presented here: his assessment of the tutorials' effectiveness for his students, how he sees his role as an instructor, and his belief that an instructor should be generous when assessing understanding.

6.5.2.1 Alan thinks that tutorials should help students with traditional problems

Alan was concerned that the tutorials were not providing the help his students needed. One reason for this was the conceptual focus of the tutorials. He felt that his students could often understand the concepts and do computations, so the problem was in putting the two together: "I don't think it's the math that's holding them back. It's the translation of intuitive ideas into algebra and then also just dealing with intuitive ideas and putting them together in various ways. It's what makes physics hard, of course." Thus, the tutorials were not helping students develop a skill that he recognized as one needing a great deal of instructional support.

The tutorials' focus on conceptual reasoning also prevented Alan's students from being exposed to aspects of physics that Alan considered fundamental, the predictive nature of physics computations and the cohesiveness of the theories. More than once he complained that tutorials presented equations as if they simply came into existence rather than showing how they derived from more fundamental laws, such as Newton's laws. He also felt that deemphasizing quantitative reasoning meant that students would not be exposed to one of the most important features of physics, the ability to quantitatively predict what would happen to physical systems.

Alan's focus on quantitative problems aligns with the ways his students were assessed. Their grades were largely based on quantitative problem solving. Alan noticed this mismatch, saying, "I'm seeing a lot of frustration from my students, about the homework and what they're being graded on, and the fact that this is not…" He also saw this mismatch on their exams: "And the tests, they'll have a lot of sort of nonconceptual questions. And so, they're [the students] sort of in a very unpleasant situation." While Alan acknowledged that students needed conceptual knowledge, he would have chosen to spend more time working through quantitative problems during the time allotted for the tutorials. Alan viewed the mismatch between what the tutorials were asking the students to do and what the students were being graded on as unfair. Alan's concern that tutorials did not prepare his students for their tests was separate from his belief that tutorials did not teach important aspects of physics as a discipline. However, both supported the same conclusion that tutorials did not provide what his students needed.

6.5.2.2 Alan treats his students as epistemologically sophisticated equals

Alan talked about his role as a tutorial TA as one in which he was monitoring the students so that they did not "get stuck" for too long. He compared his role to that of a "fifth group member who …has taken the course before… and who happens to know everything, you know, and so you can ask him." This analogy is consistent with the method of guidance Alan uses. Alan might explain a problem to a fellow graduate student and then expect that she would work to really understand that solution herself; he expects his tutorial students to do the same. Alan also explained that he could have a closer relationship with his students than their professor, who is necessarily distanced from them.

Alan often drew upon his past experiences as a learner when deciding what is appropriate and useful for his students. When explaining how it is frustrating for students when a teachers expects they will have an incorrect answer, he discussed memories of his work being marked wrong in high school, even though it was correct, because it was not in the form the teacher wanted. He backs up his opinion that the tutorials let students struggle too much by saying that when he has wrestled with something it is annoying to receive only indirect assistance. He agrees with the premise that traditional discussion sections are not effective, because he remembers finding them "deathly boring." While Alan knew that his students were beginning physics learners (and would likely never become experts), he drew on his experiences as someone who excelled in physics when determining what would help his students learn. In all of these ways, he treated his students as he would want to be treated.

6.5.2.3 Alan thinks teachers should give students the benefit of the doubt

Alan's assessment that students can be frustrated when tutorials expect they will have an incorrect answer, which was based in part on his own experiences in school, is part of a larger belief about how he should treat his students. Alan thinks it is important to give students the benefit of the doubt, a theme we see in many of his statements. He views an assumption that a student will make a mistake as insulting to the student. Likewise, when a student asks a question, he thinks a teacher should assume that student has already thought carefully about the problem. Alan also objected to the tutorials' common tactic of eliciting a common-sense idea that will need to be reconciled with a physics concept. He cited an example:

> "And then the whole rest of the tutorial assumes that they screwed up. So basically, it assumes that they, I mean, they were stupid… I'm seeing that every time I do the tutorial, there's at least one group every time, who doesn't make the stupid mistake. And then they feel, actually, kind of offended."

In Alan's view, such an assumption not only demeans a student who originally had the correct answer, but it also can cause her to be confused about something she initially understood.

Through our interviews, we came to see Alan as a TA who thought deeply about the tutorials he taught and had identified substantive differences between his expectations and those of the tutorials. He was frustrated that students using tutorials could not connect qualitative and quantitative reasoning as well as he expected. He worked to help students so they did not unnecessarily struggle. Lastly, he held a principled view that it is wrong for instructors to assume students do not understand.

6.5.3 "Co-Construction" as an alternative to confrontation

One pedagogical approach to changing Alan's beliefs might be to challenge his beliefs by presenting him with evidence that some are not appropriate or useful in the classroom. This would be similar to the "Elicit-Confront-Resolve" approach that has been used with students (Shaffer & McDermott, 1992). If a TA has such a well-established belief that it is evidenced in both his behavior and his reflections about teaching, then that belief should be stable enough so that a TA could explicitly compare the belief to evidence. This would allow him to discover the belief's shortcomings.

There are several difficulties with using ECR in TA PD. One is that the subject matter is students, not science. It can be difficult for TA instructors to find results that unambigously demonstrate that a targeted teaching technique is either good or bad. Teaching involves maneuvering through situations that involve numerous variables, including different students, varying topics, and individual instructor differences. This makes it difficult to present evidence that TAs' particular beliefs and behaviors are problematic. For example, when TAs are confronted with evidence that practices like lecturing are less effective, it may be difficult for them to determine whether the shorter explanations they might give in a tutorial might also be ineffective. Some TAs we have talked to agree that lecturing in classes is ineffective, but also state that tutorials provide the opportunity for students to hear small, focused explanations addressing their particular difficulties. Unlike an introductory physics class, where it might be easier to devise experiments showing, for example, that charges are not "used up" in a bulb, the interactions between instructors and students contain many contextual issues that can cloud an argument that a particular teaching method is wrong. A second reason to reconsider using ECR in TA PD is that it can be difficult to treat TAs as partners in the endeavor of educating students while simultaneously confronting their beliefs as "wrong." Although as TA instructors we may have the license to confront TAs' wrong ideas, it is not a privilege we should necessarily use. Confrontation makes it more difficult to establish an environment where TAs can discuss their difficulties and consider alternatives to their current teaching practices. These are good reasons to reconsider the professional development approach of confronting TAs.

We are suggesting an alternative to ECR, which we call *co-construction.* We use the term to refer to a professional development method in which the TA instructor seeks to understand the ideas that a TA brings to his teaching, and to create an environment where TAs can understand the TA instructor's recommendations for teaching. Given data, people *can* change the way they think about teaching and learning, but we think that confrontation is an inappropriate metaphor. There is preliminary evidence that such PD can provide experiences that lead to changes in how instructors think about teaching (Close & Scherr, 2010). We want to emphasize that co-construction allows for disagreement among participants. We are not advocating a technique that gives approval to each and every TA behavior. However, ECR does not provide an avenue for authentic disagreements, but rather a line of reasoning that is carefully structured to show the inadequacies in the TA's beliefs. Co-construction provides a means for TAs and TA instructors to authentically discuss differing positions, with the goal of improving teaching practice.

In the remainder of this paper, we will provide an example of what PD that uses co-construction, rather than confrontation, might look like. We will begin by describing how we are better able to understand what motivates Alan's actions when we analyze his teaching with a respectful perspective, and then we suggest activities that could be part of a responsive PD program for Alan.

6.5.4 Courtesy to Alan: Interpreting Alan's actions in terms of his values and beliefs

Looking at Alan's teaching in the previous episodes through a more respectful lens allows us to better explain why he made certain choices. In this section, we re-examine the two episodes of Alan's teaching with the goal of understanding how his actions align with the beliefs that we have just discussed. These reinterpretations help us understand why Alan's actions seem reasonable to both him and his students. In Section 6.5.4, we then show how this deeper understanding can help us identify productive resources and beliefs that Alan has, which can be used as a basis for more responsive PD.

6.5.4.1 Reinterpreting Episode 1: Alan helps his students get "unstuck"

Alan's efforts to help these students solve the problem align with his beliefs about what he and his students should be doing in tutorial. Because Alan is concerned that tutorials do not allow students to translate conceptual ideas into algebra, he is demonstrating how to do that. He is helping them do a quantitative problem, which is a part of physics he particularly values, and this problem will help prepare them for typical homework problems. His respect for the students as learners fits with his belief that it is important to assume students understand what they are doing. In addition, his conviction that a teacher owes it to his students to answer their questions helps him see this as a reasonable action.

Alan gets feedback from the students in this episode that indicates that his behavior is expected and desired. Like Alan, the students know that quantitative problems form the bulk of their homework. Many introductory physics students have had previous classes that lead to expectations that science learning is mainly about problem solving, and that a TA's role in a discussion section is to explain (rather than, say, better understand a student's idea or help them learn from their group members). While we can only speculate as to these students' experiences, they show that Alan's behavior aligns with their expectations. Student 3 has indicated that they need help. Alan is providing this help with an explanation, and they endorse this by answering questions when he asks them, focusing their gaze mainly on him, and not introducing any other ideas. In this way, there is a stable interpretation of the situation: the students ask for help and Alan provides it. Thus, the students are satisfied that they have an answer and Alan is satisfied that he has helped them.

6.5.4.2 Reinterpreting Episode 2: Alan gives a direct answer to a challenging question

From his view, Alan's behavior in the episode makes sense. Alan sees his job as helping his students complete the tutorials. Here, he sees a problem: he needs to help Student 1 understand why something can have no net force acting upon it and yet be moving. Alan must think before answering this question, and if he considers this question challenging to himself, he probably also considers it challenging for Student 1. The combination of a difficult question, an explicitly stated need, and his view that his job is to help mean that he needs to offer assistance.

Alan assists by providing the answer. When Alan is the learner, he prefers to receive a direct answer to his question, because he does not ask for help unless he has already struggled with a problem. Presumably Alan then works to make sense of the answer he is given. If Alan expects the same of his students, then his behavior is reasonable: he assumes that a question asked demonstrates sufficient thought, and that the students can make sense of the answer when he gives it to them. Moreover, Alan thinks that when students do not get a direct answer, they are frustrated. He is equally frustrated as a learner in this situation and sees no pedagogical advantage to not answering the question. Thus, directly answering Student 1's question is the decent thing to do.

In contrast to the previous episode, the students in this episode vary in their support of Alan's framing. Although Alan sees his job as answering a question, only Student 1 acts in a way that encourages him to do so. Student 1 shows Alan that she is listening to his mini-lecture with affirmations and by repeating his concluding idea (lines 72-3, 75). There are indications that at least two of the students would prefer that Alan not give such a detailed answer: Student 4 interrupts Alan to express her reply to Student 1's question (lines 17, 22-27), S2 quietly points out at the end that her idea was the same as Alan's (line 79), and neither of them asks any question of Alan, nor talks to him except to apologize for interrupting him. Nonetheless, they do not interrupt him once he begins presenting his examples. It may be that the students' understanding of what is acceptable behavior in a discussion section (a TA providing a mini-lecture) and their expectations about who has more authority to decide the activity in a class (the instructor) mean that Students 2 and 4 only provide minimal feedback to Alan that they do not endorse the Alan's purpose during the interaction.

In the re-analysis of this section, Alan's actions appear more understandable. In both of the episodes, Alan acts in alignment with his beliefs that connecting qualitative and quantitative reasoning is important, that students should have their question answered, and that students should not unnecessarily struggle. We see that Alan is working hard to teach the parts of physics that he thinks are important and that he wants his students to succeed in the class. His intentions are admirable, but the result of his teaching differs from what the tutorial developers intend for students to be doing when using tutorials. The next section discusses what productive seeds we see in Alan's beliefs. We would like to cultivate these productive seeds so that his tutorial teaching more closely aligns with our intended practices.

6.5.5 Productive seeds for professional development

Just as we often cannot easily change students' incorrect ideas about physics, we cannot easily replace teaching practices that we do not like. As we have shown, Alan's teaching is rooted in his beliefs about what physics should be taught and what help is appropriate for his students. Alan is unlikely to embrace PD that admonishes him to discard these beliefs. What we can do, however, is offer PD that builds on productive seeds in his beliefs and thereby encourages beliefs and practices that are more appropriate to reformed physics instruction.

6.5.5.1 Alan's view of his students

One of the areas in which we see productive seeds is Alan's view of his students: he sees them as epistemologically-sophisticated equals. This is not to say that he thinks that they have as much content knowledge as he does, but rather that he thinks that they have the same abilities to make sense of new physics ideas as he does. Alan's respect for his students contrasts with an unfortunately common instructional view that students are dim or unmotivated. In these episodes, Alan seems to think his students are like him. In particular, the way in which he checks his students' understanding shows that he thinks they are capable of monitoring their own understanding – perhaps even that they are co-equals with him in this respect. He overestimates their self-monitoring ability, but it is commendable that he thinks they can do it. We would have less enthusiasm for a teacher who had the view that only the teacher can judge student understanding.

In order to make Alan's generous estimation of his students' abilities productive, we might guide him to focus on how he can think more like his students, so that he can better anticipate and understand the their difficulties and abilities. Activities with this goal would build on Alan's feelings of fellowship with the students while helping him to appreciate the differences in their learning practices.

6.5.5.2 Alan's view of his job

We can also identify productive seeds for PD in Alan's desire to "do right" by his students. In both episodes, Alan has interpreted his job in the moment as answering a question, and he does not leave until he feels the students understand the answer. While we do not agree with his strategy of providing direct answers, which does not allow for extensive student participation (either in clarifying the problem or in constructing the solution), his teaching decisions align with his desire to help his students. For Alan, "doing right" by his students means affirming their possible understanding. From our perspective, assuming students' ideas are correct can often be detrimental to them because it can cause us to miss problems they have. Responsive professional development would harness Alan's desire to help his students do well, but would direct this desire toward reflection about what students ought to learn and how he can help them do that.

6.5.5.3 Alan's acknowledgement of and response to difficult conceptual questions

Although Alan believes that the conceptual questions in the tutorials are usually easy for students, Alan can recognize exceptions. For example, Alan recognizes in Episode 1 that it is difficult to understand how something can be moving but have no force on it. His rhetorical question, “How shall I put this?” (Episode 1, line 29) suggests that he has to think before he can best answer S1’s question. The cognitive resources that helped him identify this exception are resources that PD could build on to help Alan see other conceptual issues with which his students might have problems.

Alan agrees with some of the pedagogical strategies that the tutorials use, sometimes without realizing it. During both episodes, Alan provides his answers in the form of small learning progressions. Tutorials are based on such learning progressions, which guide the students through manageable steps towards the target concept. Frustrating though it may be for TA instructors to see Alan use a progression of ideas that is similar to that of the tutorials and yet not recognize the similarity, Alan’s (tacit) recognition that such progressions are useful is a productive resource.

6.5.5.4 Alan’s view of small group activities

We also see productive seeds in Alan’s assessment of traditional discussion sections, in which TAs typically work problems at the board in front of students. Alan considers these boring and ineffective. He says that they are only occasionally helpful for students, such as when the students have prepared by completing the homework before the section. “So, so that’s really boring and I’m not surprised that people don’t learn much from it. You just kind of tune out. Um, making [the students] do it would be good.” Instead of a TA lecturing, he agrees that group work is more effective, because students can build on each other’s good ideas and catch each other’s mistakes. From these comments, we can see that Alan is already convinced that traditional discussion sections offer limited opportunities for student learning. His recognition of the need for reformed methods of instruction and the usefulness of group work for student learning are productive resources.

Looking at Alan through a respectful lens allows us to see resources and beliefs he has that could be the basis for more effective professional development. The next section examines Alan's judgment of the PD he had and what changes could be made to make his PD responsive.

6.6 Responsive TA Professional Development

6.6.1 Alan's reaction to the PD he received

The open-ended questions that were asked during Alan's interview did not specifically solicit his views about the PD he was receiving. During his two interviews, however, Alan made many points that referenced the PD sessions. Most of these comments addressed two major ideas: the appropriateness of the challenge tutorials present to students and the tutorials' conceptual focus.

6.6.1.1 Appropriateness of the challenge

Alan reported that his students thought the tutorials were too easy and his experiences by the third week of teaching (when he was first interviewed) confirmed this view. He explains, "I thought… when we were originally presented with this stuff that everybody would be struggling with this and nobody would be able to get any of this... That's not happening. I mean, I've seen a lot of people who do already understand." His students' complaints about the lack of difficulty also fit with his interpretation of what he was being told during his PD,

> "The thing is, unfortunately they're [the students are] right. I mean, it is. This is high school level. I mean, of course, one could make the claim, and Rachel [the TA supervisor] does, some of this has come up in, in training sessions, that people saw this in high school and didn't get it. And, that's true… And honestly, these students are older now, and more mature, and one would hope that they would be able to, that, that they'd get it the first time."

Thus, though Alan heard in his training meetings that students need this kind of instruction, his students and his expectations both contradicted this idea.

It might be hard to imagine how Alan could experience his students as having few conceptual problems with topics such as Newton's Third Law, especially in the context of tutorials designed to help students examine their intuitions. The episodes we have discussed, though, show how Alan's interactions with his students may have reinforced his generous assessment of them. For example, in episode 1, Alan narrowly constrains how his students can respond, which makes it easier for them to provide the answer he is looking for. He then interprets their answers as further support for his belief that they understand, setting up a stable feedback loop.

6.6.1.2 Tutorials' conceptual focus

Alan's assessment of the ease of tutorials was also connected to his belief that the tutorials do not cover a difficult and important part of physics: quantitative reasoning. Alan had heard the TA instructor's claims that the tutorials helped students' scores on the Force Concept Inventory (FCI), but he interpreted an FCI gain as an insufficient goal in an introductory course. He noted that students needed more than concepts to truly understand physics: “I believe the results of the Force Concept Inventory, that I buy. But the Force Concept Inventory, how do I put this, this is designed to get you to pass the Force Concept Inventory. It does not test a whole range of things that would also be good to learn.” He also felt that the students’ problem solving skills were not improving enough, quoting the TA instructor: This is a phrasing that was given to me by Rachel, ‘Tutorials do not harm students’ ability to do problem sets.’ And I can, I can almost believe that, but it depends on what you mean by “do not harm.” If they started at the same abysmal level and you tested it and they stayed at an abysmal level.” Although the training that Alan received attempted to specifically address the idea that students who use tutorials can solve problems as well as students receiving traditional instruction, this did not ease his concerns.

We speculate that Alan’s judgment that his students’ problem solving skills are insufficient may be attributable to his limited teaching experience. Alan has only two experiences which can help him determine where to appropriately set his expectations for his students: his own undergraduate experiences (where he was most likely an above-average student) and his current students, who use tutorials yet cannot solve problems that he considers straightforward.

The PD that we provided Alan did not sufficiently prepare him to teach tutorials as the tutorial developers expected they would be taught. This failure was not Alan’s fault, and it was not due to a lack of effort on our part. Instead, the PD did not succeed because it was not responsive to Alan’s beliefs. Responsive PD for Alan would have elicited the concerns he had about the curriculum he was teaching and would also have helped him identify ways that he could improve his teaching.

While we analyzed Alan's interviews and teaching in this paper, we do not expect that we would have to do this thousands of times in order to identify the most important beliefs and experiences TAs draw on. As with students, there are probably common issues. But as with students, we cannot just guess their issues; we have to carefully observe and interpret their practices to learn about their ideas.

6.6.2 Improved PD for Alan would account for his beliefs

The PD that Alan received did not anticipate that he would not value the tutorials because of his concern that tutorials were failing to teach his students important parts of physics, such as how physical laws could be derived from one another and that physics provides "extremely powerful machinery that lets you get numbers and get precise and quantitative results." His PD did emphasize the importance of group work, but Alan already agreed that typical recitation sections were "deathly boring" and rarely addressed the needs of particular students. Unfortunately, and unbeknownst to his supervisors, the PD Alan received sometimes focused on convincing him of things he already believed and did not address his worry that tutorials neglect the quantitative part of physics.

Responsive PD is made possible when TA instructors create opportunities for TAs to express their beliefs and opinions and then tailor the PD to address them. In addition, TAs need to feel that they are responsible for their teaching and that their contributions are valued. Literature on TA and teacher PD offers suggestions to help achieve these goals. In a report advising universities on how to better prepare graduate students to become faculty, Adams (2002) called for more varied and extensive teaching experiences and PD programs that incorporated experienced TAs as resources. She suggested following the accepted apprenticeship model for training graduate students in research, in which progressively less scaffolding is provided as more responsibility is conferred. Research specifically addressing science TAs has recommended that departments provide discipline-specific pedagogical content knowledge (Marincovich, 1998) and increase the use of formative assessment (Luft, et al., 2004; Robinson, 2000). Others emphasize providing TAs with the opportunity to integrate pedagogical ideas into their teaching by offering PD as they teach (Hammrich, 2001; Price & Finkelstein, 2006) and connecting novice TAs with more experienced instructors by asking them to observe or team teach with more experienced TAs (Belnap, 2005; Carroll, 1980; Ishikawa, et al., 2001). TA instructors could help TAs identify ways to improve their teaching by observing TAs' instruction and providing feedback (Belnap, 2005). Close (2009) has reported that directing instructors to interview peers with the purpose of understanding their ideas rather than questioning to make a point focuses the instructors' attention on teaching as making sense of students' ideas. Fennema suggests presenting PD as a situation where there are two sets of experts: the PD instructor as expert in research on learning and the TAs as possessing expert knowledge about the particular situation in their classrooms (Fennema, et al., 1996).

None of these activities are *inherently* responsive. They become responsive when they are chosen in response to the beliefs and resources the particular TAs have. In Alan's case, if a TA instructor were observing him to provide feedback, the PD could be made responsive by changing the primary focus of the feedback session from the instructor advising Alan to the instructor eliciting Alan's explanation of *why* he made particular instructional moves. This way the instructor could understand the motivations and beliefs that underlie Alan's behaviors. As we have discussed elsewhere (Goertzen, et al., 2010), the beliefs that underlie a behavior cannot be "read off" from the behavior itself, because different kinds of beliefs can underlie behaviors that look similar. Thus, feedback given to Alan needs to respond not only to behavior like his tendency to assume students understand when they provide the correct conceptual answer, but also to respond to his belief that instructors *should* give students the benefit of the doubt, rather than assume they are incorrect.

Now that we better understand Alan's beliefs, we think that a part of responsive PD for Alan could be meetings in which Alan and a TA instructor meet and watch video episodes of students in the classroom (as used by Speer (2008)). In order to "cultivate" Alan's productive seed that students are capable of monitoring their own understanding, we might show him different clips of students working when the TA is not assisting them, and ask him how accurately the students seem to be evaluating their own understanding. Our purpose would be to give Alan the opportunity to observe and reflect on a wider spectrum of student metacognition. Similarly, we could build on Alan's desire to "do right" by his students by showing him the same video clips, but this time focusing his attention on whether the students have a correct conceptual understanding. This would be done to allow Alan the chance to see and become aware of a wider range of student understanding. As a third example, we would build on Alan's awareness that conceptual questions can be difficult by giving him the opportunity to modify the tutorials for future semesters. If these modifications were suggested after he had watched his students working on the tutorial, we would hope this would encourage reflection about what difficulties he sees his students having and how the tutorial could address those difficulties.

There are many reasons to think that such an approach would have the potential to help Alan improve his teaching. He cares about his students and wants to help them learn. He has demonstrated an ability to be reflective about his students' learning during his interviews. He thinks student group work is a productive activity, so watching videos of student group work would hopefully be acceptable to him as a way to see how they learn. All of these are resources that he can draw upon when improving his own instruction.

6.7 Conclusion

The initial implementations of our professional development program had been directed by our concern with the pedagogy, not the TA. Thus, we paid attention to how to "fix" the TAs' ideas, rather than attending to the substance of the TAs' ideas. We believe that what matters in not the *act* of focusing on TAs' ideas but *why* one is focusing on those ideas. If TA instructors are attending in order to assess and correct TA instruction, then it is much harder to understand the TA's motivation, and harder to provide professional development that is responsive to the particular TA's relevant concerns. Instead, responsive PD should be based in a respectful view of the TAs that acknowledges the beliefs that underlie their teaching decisions and seeks productive resources in those beliefs, which effective PD can be built upon.

We now view Alan's teaching goals as essentially noble, though mismatched with ours. He values the quantitative predictions that physics can provide, and seeks to foster the skills that lead to this. He also endeavors to treat his students with respect, which includes giving them the benefit of the doubt when they ask a question or tell him an answer.

The way we first characterized Alan's teaching was not incorrect; we were identifying pedagogical decisions to which we objected. However, our focus on what Alan did wrong instead of the reasons why he did it caused us to miss opportunities to provide him with useful PD. Only now do we have hope of designing effective PD for Alan and others like him. In general, our study of Alan tells us that we can benefit from knowing more about our TAs in order to design effective PD for all of them.

Chapter 7 Chapter 7: Summary and future directions

7.1 Summary of findings

The preceding work has shown the usefulness of examining and understanding tutorial TAs' practices in the classroom and TAs' beliefs about teaching and learning. The different analyses show what TAs think about the curriculum they are teaching, what they perceive their role as a TA to be, and how their students support or challenge the TAs' interpretations. Further, the analyses show how all of these factors influence what TAs do in the classroom.

In Chapter Four, I presented a case study of Oscar, who does not buy into some aspects of the tutorials he was teaching. His lack of buy-in affects his teaching. Oscar does not value the idea of using everyday experiences as a basis for building physics knowledge, and this is reflected in the teaching episode when he instructs students to disregard the term "common sense." He thinks that the tutorials give too little guidance to students, so he provides this guidance through questions that carefully direct students to the information he wants them to have. Oscar's lack of buy-in is unfortunately representative of what I observed in UM TAs. This contrasts with the University of Colorado (CU-B) TAs, whose beliefs more closely align with the values of the tutorial developers. The differences in the social and environmental contexts between UM and CU-B suggest that the context can affect how TAs think about the tutorials they teach. Thus, TAs' beliefs influence how they teach, but the context in which they work can influence which beliefs are (unconsciously) chosen.

The next chapter presented different examples of TAs who "focused on indicators" while teaching, using relatively thin evidence such as correct answers or key words that the students understood. Again, TAs' beliefs supported this behavior. However, each TA had different beliefs that led to their focus on indicators. In fact, the two episodes involving Alan showed how different beliefs can be activated in different contexts to support the same kinds of behaviors. Alan's beliefs about his role as an instructor, that he should give students the benefit of the doubt on conceptual problems and that he should help students grapple with traditional problems, are not contradictory, but the context of each situation foregrounds different beliefs. The finding that various beliefs can support similar behavior in the classroom leads to the recommendation that professional development (PD) should address the beliefs that underlie TAs' classroom practice. PD that only targets the behavior will not be as effective, because TAs will continue to rely on the beliefs that supported the less desired behavior.

The final data analysis chapter advocated a new perspective on TA PD, illustrated with a case study of Alan. Part of treating Alan with respect was looking for and understanding the beliefs that he had about teaching and learning. That allowed me to see his teaching practices as reasonable and motivated by a desire to help his students. While I did not always agree with his teaching decisions, considering his beliefs also provided me with the opportunity to look for productive seeds in his beliefs and experiences that could be the basis for more effective PD.

7.2 Limitations of these findings

One of the limitations of this work arises from the simple fact that this work was done with particular TAs, at two particular universities, at a particular time. It is difficult to know the effect of all the contextual factors. If, instead of examining TAs at the University of Maryland and the University of Colorado, I had examined TAs at a different university, the demographic characteristics of the TAs and their beliefs and knowledge, might have been different. For example, TAs who were less fluent in English might find communication with their students to be a primary concern; this was rarely an issue for the TAs I studied. Similarly, the characteristics of the students and the universities would be different. If I had studied TAs who taught students majoring in the physical sciences, those students might see physics as more immediately applicable to their chosen field. These students might value physics differently than students in the health and life sciences, which would in turn influence their interactions with their TAs.

Another limitation that all the TAs was voluntary participants in the study. A majority of the solicited TAs at both the University of Maryland and the University of Colorado agreed to be interviewed, but we cannot know why they participated, or why others declined. It may be that those who agreed to participate were particularly interested in improving their teaching, or were more likely to be outspoken about their concerns and problems with the system in which they were working.

7.3 The value of this dissertation to Physics Education Research

This dissertation aims to add to the field of Physics Education Research by drawing attention to a situation in physics education, TA instruction of undergraduates, which has the potential to have great impact and which has been minimally researched. PER can benefit from paying more attention to TA instruction in at least three ways. First, when TAs' instruction is improved, it can improve undergraduate learning as well as undergraduates' attitudes about physics. Next, TAs who are teaching using research-based curricula are forming their opinions about reformed instruction and the value of PER; an unsuccessful experience may impact their future willingness to consider using reform materials or color their interactions with the PER community. Lastly, a significant portion of future physics faculty will hold a TA position at some point; this TA position may be most (or all) of the teaching experience they have before running their own class.

I also extend to TA research the theoretical position, stemming from the resource framework, that sees value in understanding and building on students' naïve ideas. By applying this idea to the professional development of TAs, I hope to encourage the PER community to treat TAs as partners in the undertaking of educating students and not as either holders of pedagogical misconceptions nor as blank slates, as sometimes seems the case.

7.4 Directions for future research

One way this work could be extended is to explore how different TA practices affect their students' learning. In Chapter Five, I discussed TAs' focus on indicators, when TAs use relatively thin evidence to determine student understanding. We expect that this practice prevents TAs from noticing when students might need additional assistance. However, we do not know how this actually affects students. If students have a tutorial TA who focuses on indicators much more than another TA, do those students gain less conceptual understanding than the students of the second TA? Or do the common contextual elements that all the students share, such as the tutorial and the professor, mean that the effect of the TA is relatively muted?

Another area that might be explored is how graduate students are affected by their TA experience. One might speculate that teaching an introductory course could improve graduate students' physics knowledge, as many instructors feel that they only really understand a subject once they have taught it. Does teaching affect graduate students' epistemological beliefs? What pedagogical skills do TAs learn while teaching? Do TAs feel an increased confidence in their ability to teach and are they more interested in teaching after their TA experience? If future research could show specific skills that TAs gain through teaching, it could be used to support the call for increased attention to TA PD. This evidence could be convincing to physics departments, who want to provide their graduate students with the skills they will need as future faculty members, and to graduate students, who have many demands on their time, but who often expect to seek careers as professors.

Lastly, it is worth exploring how PD can be made most effective. Because the time available for TA professional development is so limited, there is pressure to use that time as efficiently as possible. Perhaps PD should focus on eliciting TA beliefs, through targeted readings and discussion groups. It might be effective to focus on TA's pedagogical content knowledge, which includes knowledge about common difficulties students have or different ways topics can be presented. It might also be the case that instruction in a typical PD course, where TA meet weekly as a group to learn about general topics, is not as useful as personalized feedback from a TA instructor who observes each TA's classroom. Alternatively, it might be the case that a graduate student TAs can serve as valuable resources to one another and form the beginnings of a professional community.

Once again, I note that the kind of in-depth analysis presented here provides important benefits for research-based professional development. However, I do not think it will be necessary to do these kind of in-depth analyses for *every* TA to whom we offer professional development. Research with students has shown that there are common issues, and the same is likely true for TAs. However, we cannot guess what these issues might be, but rather we should observe TAs' practice to build up a useful corpus of TA ideas and practices.

7.5 Implications for TA professional development

The research presented here suggests several ways PD could be improved. We can begin by paying more attention to TAs' beliefs. As discussed in Chapter Six, we need to understand TAs' beliefs before we can create PD that is responsive to these beliefs. These beliefs could be elicited in a variety of ways: open-ended surveys, journal assignments in which TAs reflect about their teaching, and video clubs where TAs watch videos of each other's teaching and discuss them. Once a TA instructor has a better understanding of how the individual TAs she is training think about teaching and learning, she can select or create activities to address particular issues and build on the productive seeds she identifies.

Another way to make PD more responsive is to offer more types of PD. Price and Finkelstein (2006) offered a tiered program, in which graduate students participate at varying levels of commitment. In their program, a TA may begin by preparing a small practice lecture (a "micro-teach") that they give to a group of fellow TAs in order to receive feedback. Other activities include developing curriculum or guest lecturing, or becoming the instructor of record of a course. These activities require different time commitments and offer greater or lesser opportunities to improve teaching skills. By offering these choices, departments would be more likely to involve TAs who are genuinely interested in the PD activity they have chosen. Such a tiered program would also improve the chances that TAs get preparation that they need; if a TA expects that he will work as a professor in the future, he may be more likely to seek PD that prepares him for that job, in comparison to a TA who expects to work in a non-teaching industry job.

This research also points to a need for departments to create a supportive teaching environment for their TAs. As Chapter Five showed, TAs absorb the larger metamessages about teaching that their departments and institutions convey. If the department and the university create programs and policies that encourage attention to improving teaching, and if these programs and policies accurately reflect the values of the department, TAs may be more likely to spend the time and effort needed to reflect upon and improve their teaching. A TA instructor alone cannot institute these kinds of changes, because a single person cannot define the norms of the community. The kinds of changes that affect TAs' context, such as giving TAs credit for PD courses they take or compensating faculty for the time they spend supervising TAs, would more likely occur when there are multiple people in the physics department committed to improving TA instruction.

7.6 Reflection: obstacles and support for improved TA PD

Improving the professional development offered to physics TAs is not an easy task. Increasing the supervision and feedback that TAs receive might mean compensating faculty who agree to mentor or train TAs, or it might mean that someone is hired specifically for this task. Offering academic credit for TAs who participate in PD courses means that departments or the grants that pay graduate student salaries are billed for extra course hours. If, as sometimes seems to be the case, the current social and environmental context does not offer much to support TAs' teaching, then the changes required could be far-reaching. Such changes have the potential to shift resources and attention away from the research that is the primary mission of many departments. It also takes time, attention, and skills to create a professional development environment where TAs feel comfortable examining their teaching practices. All of these changes require either money or time to be used differently, and those are both scarce resources in departments.

There are just as many reasons to be hopeful that TA PD can be improved. There is a large body of teacher literature that can help inform TA instructors; using it we can better anticipate the some of the difficulties new instructors face, the environmental factors that can impede or support effective teaching, and the beliefs and knowledge we might expect novice instructors to have. Next, an increasing base of research-based PD for science TAs is being published, which will minimize the need for each TA instructor to "reinvent the wheel". Departments and institutions are motivated to provide support for improved TA PD because it allows them to make progress simultaneously toward two goals: increased undergraduate learning and graduating doctoral students who are better prepared for their future careers. Lastly, I am encouraged by my experiences with TAs, who, in spite of many demands on their time, regularly approach their teaching duties with a sincere desire to help their students learn.

Appendix 1 Characterization of TA Buy-in

In order to better understand the individual TAs' buy-in, their transcribed interviews were coded. The interview questions were open-ended in order to respond to TAs' replies. A typical question was, "What do you see as the advantages and disadvantages of tutorial-style teaching, for you, and for the students?"

To develop categories, we examined a subset of TA interviews, selected quotes in which they were discussing aspects of tutorials, and then created categories from them. Thus, the categories are a reflection of the characteristics of tutorials that TAs considered noteworthy, rather than the aspects of tutorials that the developers value. After these categories were established, we coded all the transcripts from TA interviews.

If a TA discussed some aspect of tutorial, that talking turn was categorized. Individual turns were put into multiple categories when appropriate. All interviews turns were sorted into one of the categories or coded as not relating to tutorials (an example of the latter would be a discussion of how the TA learns best). Each comment labeled as predominantly showing buy-in (aligning with the developers' ideas), predominantly not showing buy-in (not aligning with the developers' ideas), or as mixed. All of the comment ratings in a category were considered together to determine a rating for each TA in each category. (Again, they were rated as predominantly showing buy-in, anti-buy-in, or as a mix.) If a TA did not mention that aspect, there is no code for that TA in that category.

One researcher did all of the coding. To check inter-rater reliability, a second researcher was given an hour of training and then was given 21 quotes to which the first researcher had assigned at least one category. For each quote, the second coder assigned categories to the quotes and coded whether the TA was bought in, not bought in, or "mixed" with respect to each category.

For the buy-in codes, there was 86% agreement, with no disagreements between "buy in" and "anti-buy-in." Instead, all the disagreements were between "mixed" and one of the other two categories.

The coders agreed on the categories assigned 79% of the time, but about half of the mismatches were due to a disagreement about whether a second category needed to be assigned (e.g., the first coder assigned two categories while the second coder assigned just one). In those cases, the coder who assigned just one category was asked to assign a secondary category. The secondary category chosen agreed, in two of the three cases, with the secondary category assigned by the other coder. In summary, the two coders disagreed on categories 21% of the time: 12% were disagreements about category choices and 9% were disagreements only about whether the "signal" from a secondary category was strong enough to warrant a category assignment.

Table 2 shows the designation each TA received in all of the categories on which he commented. The designations are indicated with colors: light blue for buy-in, medium blue for mixed (both aligned and nonaligned comments), and dark blue for anti-buy-in. A TA's comments are considered mixed if less than approximately three quarters of the comments in that category were aligned (or not aligned). If a category had no comments from a TA, the corresponding box is gray.

As an example, consider Chris, the UM TA shown in the fifth column, labeled "C." When he discussed group work, he said that he valued it for students because it gave more of them a chance to ask questions, allowed them to teach each other, and provided them with the chance to focus on their own particular difficulties. He also appreciated it as a teacher because he didn't have to devise a "50-minute show" and because it better prepared him to answer the questions he'd expect when he was a lecturer. His only concern was that having to answer student questions on the spot took more time than delivering a prepared lecture. Because his comments were predominantly aligned, his rating for this category was "Buy-in."

Chris was concerned that the qualitative focus of the tutorials did not prepare students sufficiently for the MCAT and their quantitative, multi-step homework problems. He did not suggest any positive aspects of the emphasis on qualitative physics reasoning. As a result, he was rated as "Anti-buy-in" for this category.

Chris's assessment of the structured nature of tutorials was mixed. Because the tutorials were a prepared curriculum, Chris liked the limited preparation required, but found it difficult to use material that was unfamiliar. He said that at the beginning, it "was kind of hard to be using someone else's words effectively, and I kind of got a handle on that and also got a handle on how to put my thoughts in it…." His buy-in that category was accordingly rated as "Mixed."

The UM TAs were interviewed twice, at the start and end of the semester they taught. The comments from these two interviews were combined before they were rated. The CU TAs were interviewed once, near the end of the semester they taught. We might expect that a grouping of initial and final assessments would obscure changes that occurred in UM TAs during the semester they taught. In order to estimate how much change might have occurred, we counted the number of times that we could have observed a change (i.e. the number of times a TA commented on a particular category in both the initial and final interviews), which was 57 instances. We then tallied the number of times our codes of a TA's values changed, for example from mixed to positive, which happened 17 times. This means that changes in TAs' values occurred about 30% of the time, where about two-thirds of the observed changes were positive (i.e. from mixed to positive or negative to mixed). This is not an extensive amount of change, and it is consistent with our informal observations.

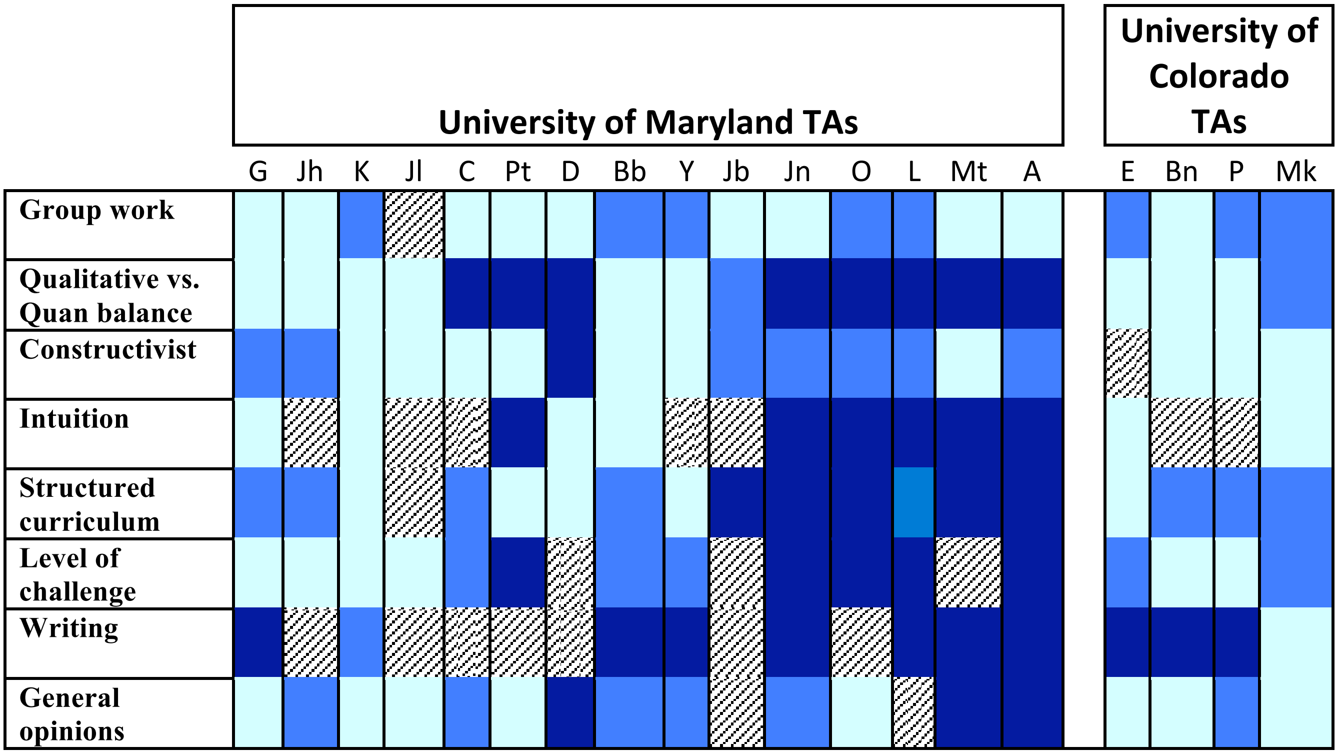
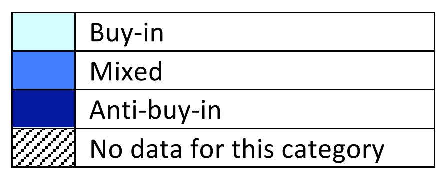


Table 2. The alignment of each TA in each category on which he commented.



Appendix 2 Interview questions

The following questions were asked during the open-ended interviews we conducted with the TAs.

1. Have you taught before?
2. How is the course going?
3. How is discussion section going?
4. What do you see as the advantages and disadvantages of tutorial-style teaching: for you? for the students?
5. How would you recommend tweaking the current format?
6. Do you think your students are learning better, worse, or the same as they would in a regular- style recitation section?
7. What's hard about teaching this way, and what's easy?
8. Do you think that the course (lecture and tutorials) help teach what students should be learning in a physics course?
9. (Asked only in the 2007 and 2008 interviews) When teaching tutorials, what did you see your job as?

Bibliography

Adams, K. (2002). *What colleges and univeqrsities want in new faculty*. Washington, DC: Association of American Colleges and Universities.

Aguirre, J., & Speer, N. (1999). Examining the relationship between beliefs and goals in teacher practice. *Journal of mathematical behavior, 18*(3), 327-356.

Allen, R. (1976). Effective training for teaching assistants. *The American Biology Teacher, 38*(1), 24-27.

Arons, A. (1976). Cultivating the capacity for formal reasoning: Objectives and procedures in an introductory physical science course. *American Journal of Physics, 44*(9), 834-838.

Bateson, G. (1972). *Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology*. San Francisco: Chandler Press.

Belnap, J. (2005). *Putting TAs into context: Understanding the graduate mathematics teaching assistant.* Unpublished PhD, The University of Arizona.

Borko, H., & Putnam, R. (1996). Learning to teach. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (Vol. 2, pp. 673-708). New York: Macmillan.

Brickhouse, N. (1990). Teachers'beliefs about the nature of science and their relationship to classroom practice. *Journal of teacher education, 41*(3), 53.

Bryan, L. (2003). Nestedness of beliefs: Examining a prospective elementary teacher's belief system about science teaching and learning. *Journal of Research in Science Teaching, 40*(9), 835-868.

Bucher, A. M. (2002). *Mathematics graduate students as they learn about teaching undergraduates.* University of Illinois at Urbana-Champaign, Urbana, IL.

Calder, A. (2006). *Graduate teaching assistants in a reformed introductory physics course: Synthesis of quantitative analyses of instructor action and qualitative analyses of instructor attitudes and perspectives.* UNIVERSITY OF CALIFORNIA, DAVIS, Davis, CA.

Carpenter, T., Fennema, E., Peterson, P., Chiang, C., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. *American Educational Research Journal, 26*(4), 499.

Carroll, J. (1980). Effects of training programs for university teaching assistants: A review of empirical research. *The Journal of Higher Education, 51*(2), 167-183.

Clark, A. (1998). *Being there: Putting brain, body, and world together again*: MIT press.

Close, E. (2008). *Teacher Characteristics and Student Learning in Secondary Science.* Seattle Pacific University, Seattle, WA.

Close, H. (2009). *Teaching the joy of learning about student thinking in physics*. Paper presented at the American Association of Physics Teachers.

Close, H. & Scherr, R. (2010) Tranformative professional development: Cultivating concern with others' thinking as the root of teacher identity. Submitted.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational researcher, 23*(7), 13.

Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Educational Evaluation and Policy Analysis, 12*(3), 311-329.

Cronin-Jones, L. (1991). Science teacher beliefs and their influence on curriculum implementation: Two case studies. *Journal of Research in Science Teaching, 28*(3), 235-250.

Crouch, C., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*(9), 970-977.

Davis, K. (2003). Change is hard: What science teachers are telling us about reform and teacher learning of innovative practices. . *Science Education, 87*(1).

diSessa, A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293-331.

Eisenhart, M., Borko, H., Underhill, R., Brown, C., Jones, D., & Agard, P. (1993). Conceptual knowledge falls through the cracks: Complexities of learning to teach mathematics for understanding. *Journal for Research in Mathematics Education, 24*(1), 8-40.

Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics, 69*(S1), S54-S64.

Elby, A., & Scherr, R. (2006). Physics 121: Tutorials and laboratories. Department of Physics, University of Maryland, College Park.: Wiley Custom Services.

Elby, A., Scherr, R., McCaskey, T., Hodges, R., Redish, E., Hammer, D., et al. *Maryland tutorials in physics sense-making, DVD, Funded by NSF DUE-0341447*.

Erickson, F. (2004). *Talk and social theory*. Cambridge, MA: Polity Press Malden.

Etkina, E. (2000). Helping Graduate Assistants Teach Physics: Problems and Solutions. *Journal of Graduate Teaching Assistant Development, 7*(3), 123-137.

Ezrailson, C. (2004). *EMIT: explicit modeling of interactive-engagement techniques for physics graduate teaching assistants and the impact on instruction and student performance in calculus-based physics.* Texas A & M, College Station, TX.

Fennema, E., Carpenter, T., Franke, M., Levi, L., Jacobs, V., & Empson, S. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for Research in Mathematics Education*, 403-434.

Finkelstein, N., Otero, V., & Pollock, S. (Fall 2006 - Spring 2007). *Teaching to Learn: The Colorado Learning Assistant program's impact on learning content*.

Finkelstein, N., & Pollock, S. (2005). Replicating and understanding successful innovations: Implementing tutorials in introductory physics. *Physical Review Special Topics-Physics Education Research 1*, 010101.

Franke, M., Carpenter, T., Fennema, E., Ansell, E., & Behrend, J. (1998). Understanding teachers' self-sustaining, generative change in the context of professional development. *Teaching and Teacher Education, 14*(1), 67-80.

Franke, M., Carpenter, T., Levi, L., & Fennema, E. (2001). Capturing teachers' generative change: A follow-up study of professional development in mathematics. *American Educational Research Journal, 38*(3), 653.

French, D., & Russell, C. (2002). Do Graduate Teaching Assistants Benefit from Teaching Inquiry-Based Laboratories? *BioScience, 52*(11), 1036-1041.

Gilreath, J., & Slater, T. (1994). Training graduate teaching assistants to be better undergraduate physics educators. *Physics Education, 29*, 200-203.

Goertzen, R., Scherr, R., & Elby, A. (2009). Accounting for tutorial teaching assistants' buy-in to reform instruction. *Physical Review Special Topics - Physics Education Research, 5*(2), 20109.

Goertzen, R., Scherr, R., & Elby, A. (2010). Tutorial TAs in the classroom: Similar teaching behaviors are supported by varied beliefs about teaching and learning. *Accepted to Physical Review Special Topics - Physics Education Research*.

Goffman, E. (1974). *Frame analysis: An essay on the organization of experience*: Harper & Row.

Golde, C., & Dore, T. (2001). *At cross purposes: What the experiences of doctoral students reveal about doctoral education*. Philadelphia, PA: Pew Charitable Trusts. www. phd-survey. org.

Greeno, J. (1997). Theories and practices of thinking and learning to think. *American Journal of Education, 106*(1), 85-126.

Greeno, J., Collins, A., & Resnick, L. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15-46). New York: Macmillan.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12*(1), 53-90.

Hammer, D., Elby, A., Scherr, R., & Redish, E. (2005a). Resources, framing, and transfer. In J. Mestre (Ed.), *Transfer of learning: Research and perspectives* (pp. 89-120). Greenwich, CT: Information Age Publishing.

Hammer, D., Elby, A., Scherr, R., & Redish, E. (2005b). Resources, framing, and transfer. *Transfer of learning from a modern multidisciplinary perspective*, 89-120.

Hammrich, P. (1994). *Learning To Teach: Teaching Assistants Conception Changes about Science Teaching*. Paper presented at the National Conference on College Teaching and Learning.

Hammrich, P. (2001). Preparing graduate teaching assistants to assist biology faculty. *Journal of Science Teacher Education, 12*(1), 67-82.

Haney, J., Lumpe, A., Czerniak, C., & Egan, V. (2002). From beliefs to actions: The beliefs and actions of teachers implementing change. *Journal of Science Teacher Education, 13*(3), 171-187.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*(7), 637-644.

Henderson, C., & Dancy, M. (2007). Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics. *Physical Review Special Topics-Physics Education Research, 3*(2), 020102.

Hollar, K., Carlson, V., & Spencer, P. (2000). 1+ 1= 3: Unanticipated Benefits of a Co-Facilitation Model for Training Teaching Assistants. *Journal of Graduate Teaching Assistant Development, 7*(3), 173-181.

Hoyle, S. (1993). Participation frameworks in sportscasting play: Imaginary and literal footings. In D. Tannen (Ed.), *Framing in discourse* (pp. 114-145): Oxford Englash Presse.

Hume, N. (2004). *The first-year teaching assistant experience in a chemistry department.* Purdue University.

Hutchins, E. (1996). Learning to navigate. In S. Chaiklin & J. Lave (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 35-65). New York: Cambridge University Press.

Ishikawa, C., Potter, G., Blickenstaff, J., De Leone, C., Castori, P., & Potter, W. (2000). *March. Changes in Physics 7 graduate student instructors' conceptions of teaching and learning following a professional development program.* Paper presented at the Meemting of the National Association for Research in Science Teaching, New Orleans, LA.

Ishikawa, C., Potter, W., & Davis, W. (2001). Beyond This Week. *Journal of Graduate Teaching Assistant Development, 8*(3), 133-138.

Jones, M. G., & Carter, G. (2007). Science teacher attitudes and beliefs. In S. K. Abell & L. M. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 1067-1104). Mahwah, NJ: Lawrence Erlbaum.

Kezar, A., & Eckel, P. (2002). The effect of institutional culture on change strategies in higher education: universal principles or culturally responsive concepts? *Journal of Higher Education*, 435-460.

King, K., Shumow, L., & Lietz, S. (2001). Science education in an urban elementary school: Case studies of teacher beliefs and classroom practices. *Science Education, 85*(2), 89-110.

Knight, P., & Trowler, P. (2000). Department-level cultures and the improvement of learning and teaching. *Studies in Higher Education, 25*(1), 69-83.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, England: Cambridge Univ Pr.

Lawrenz, F., Heller, P., Keith, R., & Heller, K. (1992). Training the teaching assistant. *Journal of College Science Teaching, 22*, 106-109.

Lawson, A., Benford, R., Bloom, I., Carlson, M., Falconer, K., Hestenes, D., et al. (2002). Evaluating College Science and Mathematics Instruction: A Reform Effort That Improves Teaching Skills. *Journal of College Science Teaching, 31*(6), 388-393.

Lederman, N. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36*(8), 916-929.

Lederman, N., Gess-Newsome, J., & Latz, M. (1994). The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. *Journal of Research in Science Teaching, 31*(2).

Levin, D. (2008). *What secondary science teacher pay attention to in the classroom: situating teaching in instutional and social systems.* University of Maryland, College Park, College Park, MD.

Levitt, K. E. (2002). An analysis of elementary teachers' beliefs regarding the teaching and learning of science. *Science Education, 86*(1), 140-165.

Lin, Y. (2008). *From Students to Researchers: The Education of Physics Graduate Students.* The Ohio State University.

Lindlof, T., & Taylor, B. (2002). *Qualitative communication research methods* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Luft, J., Kurdziel, J., Roehrig, G., & Turner, J. (2004). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching, 41*(3), 211-233.

MacLachlan, G., & Reid, I. (1994). *Framing and interpretation*. Portland, OR: Melbourne Univ. Press.

Marincovich, M. (1998). Teaching teaching: The importance of courses on teaching in TA training programs. In M. Marincovich, J. Prostko & F. Stout (Eds.), *The professional development of graduate teaching assistants* (pp. 145-162). Bolton, MA: Anker Publishing Co.

Mazur, E. (1997). *Peer Instruction: A User's Manual*. Upper Saddle River, NJ: Prentice-Hall.

McDermott, L. (2001). Oersted Medal Lecture 2001: Physics Education Research:The Key to Student Learning. *American Journal of Physics, 69*(11), 1127.

McDermott, L., Heron, P., Shaffer, P., & Stetzer, M. (2006). Improving the preparation of K-12 teachers through physics education research. *American Journal of Physics, 74*(9), 763.

McDermott, L., & Redish, E. (1999). Resource letter: PER-1: Physics education research. *American Journal of Physics, 67*, 755.

McDermott, L., & Shaffer, P. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics, 60*(11), 994-10003.

McDermott, L., & Shaffer, P. (2002). *Tutorials in introductory physics*. Upper Saddle River, NB: Prentice Hall.

McDermott, L., Shaffer, P., & Rosenquist, M. (1996). *Physics by Inquiry* (Vol. 2): John Wiley & Sons, Inc., New York.

McDermott, L., Shaffer, P., & Somers, M. (1994). Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine. *American Journal of Physics, 62*(1), 46-55.

McGivney-Burelle, J., DeFranco, T., Vinsonhaler, C., & Santucci, K. (2001). Building Bridges: Improving the Teaching Practices of TAs in the Mathematics Department. *Journal of Graduate Teaching Assistant Development, 8*(2), 55-63.

Mulvey, P., & Tesyafe, C. (2006). *Graduate Student Report: First Year Physics and Astronomy Students, 2004* (No. R-207.35). College Park, MD: American Institute of Physics.

Nespor, J. (1994). *Knowledge in motion: Space, time, and curriculum in undergraduate physics and management*: Routledge.

Neuschatz, M., & McFarling, M. (1999). *Maintaining Momentum: High School Physics for a New Millennium. AIP Report* (No. AIP-R-427). College Park, MD: American Institute of Physics.

Otero, V. (2003). *Cognitive processes and the learning of physics part II: Mediated action.* Paper presented at the International School of Physics "Enrico Fermi" Course CLVI, Varenna on Lake Como.

Otero, V. (2006). Moving beyond the "get it or don't" conception of formative assessment. *Journal of teacher education, 57*(3), 247.

Otero, V., Finkelstein, N., McCray, R., & Pollock, S. (2006). Who Is Responsible for Preparing Science Teachers? *Science and Education, 313*(5786), 445-446.

Pajares, M. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of educational research, 62*(3), 307.

Pellathy, S. (2009). *The use of representations by physics graduate teaching assistants.* University of Pittsburgh, Pittsburgh, PA.

Peterson, P. (1990). Doing more in the same amount of time: Cathy Swift. *Educational Evaluation and Policy Analysis, 12*(3), 261.

Committee on the Status of Women in Physics, (2005). Assessing Graduate Programs: Program Details. University of Maryland.

http://www.aps.org/programs/women/female-friendly/detail.cfm?id=69 Retrieved November 25, 2009, 2009

Pollock, S., & Finkelstein, N. (2008). Sustaining educational reforms in introductory physics. *Physical Review Special Topics-Physics Education Research, 4*(1), 010110.

Price, E., & Finkelstein, N. (2006). Preparing graduate students to be educators. *Arxiv preprint physics/0609003*.

Prosser, M., & Trigwell, K. (1997). Relations between perceptions of the teaching environment and approaches to teaching. *British Journal of Educational Psychology, 67*(1), 25-35.

Ramsden, P., Prosser, M., Trigwell, K., & Martin, E. (2007). University teachers' experiences of academic leadership and their approaches to teaching. *Learning and Instruction, 17*(2), 140-155.

Redish, E. (2003). *A Theoretical Framework for Physics Education Research: Modeling Student Thinking.* Paper presented at the International School of Physics "Enrico Fermi" Course CLVI, Varenna on Lake Como.

Redish, E., & Hammer, D. (2009). Reinventing college physics for biologists: Explicating an epistemological curriculum. *American Journal of Physics, 77*(7), 629-642.

Robinson, J. (2000). New Teaching Assistants Facilitate Active Learning in Chemistry Laboratories: Promoting Teaching Assistant Learning through Formative Assessment and Peer Review. *Journal of Graduate Teaching Assistant Development, 7*(3), 147-162.

Roehrig, G., Luft, J., Kurdziel, J., & Turner, J. (2003). Graduate teaching assistants and inquiry-based instruction: implications for graduate teaching assistant training. *Journal of Chemical Education, 80*, 1206.

Rop, C. (2002). The Meaning of Student Inquiry Questions: A Teacher. *International Journal of Science Education, 24*(7), 717-736.

Roth, W., McGinn, M., Woszczyna, C., & Boutonne, S. (1999). Differential participation during science conversations: The interaction of focal artifacts, social configurations, and physical arrangements. *Journal of the Learning Sciences, 8*(3), 293-347.

Rushin, J., De Saix, J., Lumsden, A., Streubel, D., Summers, G., & Bernson, C. (1997). Graduate Teaching Assistant Training: A Basis for Improvement of College Biology Teaching & Faculty Development? *The American Biology Teacher, 59*(2), 86-90.

Sawada, D., Piburn, M., Judson, E., Turley, J., Falconer, K., Benford, R., et al. (2002). Measuring Reform Practices in Science and Mathematics Classrooms: The Reformed Teaching Observation Protocol. *School Science and Mathematics, 102*(6), 245-254.

Schank, R. (1980). Language and memory. *Cognitive Science, 4*(3), 243-284.

Scherr, R., & Elby, A. (2006). *Enabling Informed Adaptation of Reformed Instructional Materials.* Paper presented at the Physics Education Research Conference.

Schoenfeld, A. (1998). Toward a Theory of Teaching-in-Context. *Issues in Education, 4*(1), 1-94.

Schroeder, C., Scott, T., Tolson, H., Huang, T., & Lee, Y. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching, 44*(10), 1436-1460.

Seung, E. (2007). *Examining the development of knowledge for teaching a novel introductory physics curriculum.* Purdue University, West Layafette, IN.

Seymour, E. (2005). *Partners in innovation: Teaching assistants in college science courses*. Boulder, CO: L.Rowman and Littlefeld.

Seymour, J., & Lehrer, R. (2006). Tracing the evolution of pedagogical content knowledge as the development of interanimated discourses. *Journal of the Learning Sciences, 15*(4), 549-582.

Shaffer, P., & McDermott, L. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of an instructional strategy. *American Journal of Physics, 60*(11), 1003-1013.

Shulman, L. (1986). Those who understand: Knowledge growth in teaching. *Educational researcher, 15*(2), 4-14.

Simmons, P., Emory, A., Carter, T., Coker, T., Finnegan, B., Crockett, D., et al. (1999). Beginning teachers: Beliefs and classroom actions. *Journal of Research in Science Teaching, 36*(8), 930-954.

Smith III, J., diSessa, A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences, 3*(2), 115-163.

Sokoloff, D., & Thornton, R. (2004). *Interactive Lecture Demonstrations, Active Learning in Introductory Physics*. New Yok: John Wiley and Sons.

Southerland, S., Johnston, A., & Sowell, S. (2006). Describing teachers' conceptual ecologies for the nature of science. *Science Education, 90*(5).

Speer, N. (2001). *Connecting beliefs and teaching practices: A study of teaching assistants in collegiate reform calculus courses.*

Speer, N. (2008). Connecting Beliefs and Practices: A Fine-Grained Analysis of a College Mathematics Teacher's Collections of Beliefs and Their Relationship to His Instructional Practices. *Cognition and Instruction, 26*(2), 218-267.

Stetzer, M. (2010, February 15, 2010). *Professional development of graduate TAs: The role of PER.* Paper presented at the American Association of Physics Teachers, Washington, DC.

Tannen, D. (1993a). What's in a frame? Surface evidence for underlying expectations. In D. Tannen (Ed.), *Framing in discourse* (pp. 14-56). New York: Oxford English Press.

Tannen, D. (Ed.). (1993b). *Framing in discourse*. New York: Oxford University Press, USA.

Tannen, D., & Wallat, C. (1993). Interactive frames and knowledge schemas in interaction: Examples from a medical examination/ interview. In D. Tannen (Ed.), *Framing in discourse* (pp. 57-76). New York: Oxford Englash Press.

Tobin, K., & McRobbie, C. (1997). Beliefs about the nature of science and the enacted science curriculum. *Science and Education, 6*(4), 355-371.

van Driel, J., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673-695.

Volkmann, M., & Zgagacz, M. (2004). Learning to teach physics through inquiry: The lived experience of a graduate teaching assistant. *Journal of Research in Science Teaching, 41*(6), 584-602.

Wiemers, N. (1990). Transformation and accommodation: A case study of Joe Scott. *Educational Evaluation and Policy Analysis, 12*(3), 281.

Wilson, S. (1990). A conflict of interests: The case of Mark Black. *Educational Evaluation and Policy Analysis, 12*(3), 293.