

ABSTRACT

WESTLANDER, MEGHAN JOANNE. The Issues Framework: Situating Graduate Teaching Assistant-Student Interactions in Physics Problem Solving. (Under the direction of Robert Beichner.)

Interactive engagement environments are critical to students' conceptual learning gains, and often the instructor is ultimately responsible for the creation of that environment in the classroom. When those instructors are graduate teaching assistants (GTAs), one of the primary ways in which they can promote interactive engagement is through their interactions with students.

Much of the prior research on physics GTA-student interactions focuses on GTA training programs (e.g. Ezrailson (2004); Smith, Ward, and Rosenshein (1977)) or on GTAs' specific actions and beliefs (e.g. West, Paul, Webb, and Potter (2013); Goertzen (2010); Spike and Finkelstein (2012a)). Research on students' ideas and behaviors within and surrounding those interactions is limited but important to obtaining a more complete understanding of how GTAs promote an interactive environment.

In order to begin understanding this area, I developed the Issues Framework to examine how GTA-student interactions are situated in students' processes during physics problem solving activities. Using grounded theory, the Issues Framework emerged from an analysis of the relationships between GTA-student interactions and the students procedures and expressions of physics content in and surrounding those interactions.

This study is focused on introducing the Issues Framework and the insight it can provide into GTA-student interactions and students' processes. The framework is general in nature and has a visually friendly design making it a useful tool for consolidating complex data and quickly pattern-matching important pieces of a complex process.

Four different categories of Issues emerged spanning the problem solving process: (1) Getting Started, (2) Solution Approach, (3) Unit Conversions, and (4) Other. The framework allowed for identification of the specific contents of the Issues in each category as well as revealing the

common stories of students' processes and how the interactions were situated in those processes in each category.

Through the stories, the Issues Framework revealed processes in which students often focused narrowly on procedures with the physics content expressed through their procedures and only sometimes through conceptual discussions. Interactions with the GTA affected changes in students' processes, typically leading students to correct their procedures. The interactions often focused narrowly on procedures as well but introduced conceptual discussions more often than students did surrounding the interactions. Comparing stories across GTAs instead of across categories revealed one GTA who, more often than other GTAs, used conceptual discussion and encouraged students' participation in the interactions.

The Issues Framework still needs continued refinement and testing. However, it represents a significant step toward understanding GTA-student interactions from the perspective of students' processes in physics problem solving.

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The Issues Framework: Situating Graduate Teaching Assistant-Student Interactions
in Physics Problem Solving

by
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DEDICATION

To Brian, whose continued encouragement, support, and faith made this possible.

BIOGRAPHY

Meghan Joanne Westlander grew up in a suburb of San Francisco, attending Catholic school through high school. While she was always interested in relationships and communication among people, her interest in physics began blossoming her senior year of high school. She became fascinated with special relativity and astrophysics, reading a slew of books from the local library.

Beginning college at the University of California, San Diego, she did not know which interest to follow first, changing majors several times. She eventually majored in Physics with a specialization in Astrophysics while minoring in Math and Psychology.

Upon graduating college in 2004, Meghan pursued her interest in physics, interning at NASA Goddard Space Flight Center and working temporarily for General Atomics. In 2005, she changed course and joined Teach for America, teaching physics and physical science to high school seniors and freshman in St. Louis, MO. Teaching solidified a desire to pursue a career that encompassed her interest in human relationships *and* physics combined with a new interest in educational reform.

Through previous contacts, Meghan connected with Tom Foster at Southern Illinois University, Edwardsville and worked with him on a pilot study in Physics Education Research. This fueled her interest in continuing research in the field, and she applied to graduate programs across the country. She was accepted to North Carolina State University beginning in Fall 2008. Prior to entering graduate school, Meghan took some time to enjoy the California mountains with her husband, spending her final three months before graduate school hiking a portion of the Pacific Crest Trail.

While at school at NC State, Meghan continued expanding her teaching experience as well as developing research experience. Three influential teaching experiences were opportunities to: co-design and co-lead a professional development workshop in physics for in-service elementary school teachers, assist in teaching the Physics in Everyday Thinking curriculum to pre-service teachers, and assist in teaching Matter and Interactions in a SCALE-UP classroom. Her teaching

experience fueled a deeper interest in helping her students connect with physics conceptually.

Her research reflects her desire to better understand human relationships in physics classrooms. Her interest in this research is also personal, born from continuous reflection on her own experiences with her students. She hopes her project will be helpful both to future researchers interested in studying teacher-student interactions and to teachers who share an interest in understanding their own connections with their students through interactions.

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Many people have helped me on this journey, contributing in valuable ways to my education, my progress, and my sanity. I am consistently inspired by the love and support I have received and am eternally grateful for the amazing people in my life.

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Chapter 1

Introduction and Overview

Physics education research (PER) has shown that students' conceptual learning gains improve more in environments that use interactive engagement methods (Hake, 1997; Redish & Steinberg, 1999). Interactive engagement methods are described by Hake as methods that are, "...designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors." Though curricular and pedagogical tools aid in making courses more interactive, it is ultimately the physics course instructors' responsibility for creating an interactive environment within the classroom. Often, these instructors are Graduate Teaching Assistants (GTAs) assigned to teach labs and recitation sections.¹ One of the primary ways in which GTAs can promote interactive engagement in these classes is through their interactions with students, making GTA-student interactions a valuable area to research.

Much of the prior research on physics GTA-student interactions focuses on GTAs' specific actions or beliefs, providing valuable information into how GTAs interact with students and why they may do so in particular ways (West et al., 2013; Kyle, Penick, & Shymansky, 1980; Goertzen, 2010; Spike & Finkelstein, 2012a). Other research focuses on GTA training programs, giving insight into how GTAs' interaction behaviors might change with particular

¹In some courses, GTAs may also teach alongside a primary instructor (R. J. Beichner et al., 2007).

training (Ezrailson, 2004; Smith et al., 1977; Pellathy, 2009). However, research on students' ideas and behaviors within and surrounding those interactions is limited. Understanding this aspect of interactions is very important to obtaining a more complete understanding of how GTAs promote an interactive environment.

Prior research speculates that characteristics of GTA-student interactions might affect students' behaviors both within and outside those interactions (Irving, Martinuk, & Sayre, 2013; Karelina & Etkina, 2007; West et al., 2013). Research by Irving et al. (2013) on students' framing shows that GTAs often help students change frames during an interaction. And, Karelina and Etkina (2007) describe examples showing that GTAs have the ability to help students continue sense-making or hinder it by how they respond to the students in interactions. Some of their evidence also shows students repeatedly follow up sense-making with asking the GTA a question and getting a direct answer.² West et al. (2013) also noticed a similar pattern in their study: students waiting for a GTA and then receiving information.³ They speculate that students to whom the GTA explains more may be more likely to wait for a GTA's help than to continue attempting to work through something difficult on their own.

Overall, research in this area is still sparse, but what exists supports the importance of studying both the GTA-student interactions and the students outside of interactions. I propose to continue studying interactions and students' actions outside interactions by designing a framework that outlines the characteristics of these interactions and the students' processes before and after those interactions. The framework provides a basis for examining the influence of GTA-student interactions on students, leading to a better understanding of how GTAs promote interactive engagement in their classrooms.

To prepare for this framework, Chapter 2 will explore previous research on GTA-student interactions in the classroom, providing the background for the current study. Chapter 3 will provide the study design and methods used to collect and process the data from which the

²These instances occurred frequently in a traditional lab setting. In the non-traditional lab, students tended to follow up sense-making with procedures.

³Their research was done exclusively in an interactive engagement course and only on GTAs' interaction behaviors.

framework emerges. I present analysis methods and the full design of the framework in Chapter 4. Initial results of the application of the framework will be examined in Chapter 5, and Chapter 6 will discuss conclusions and areas of future work. The rest of this first chapter will offer further motivation for the study as well as some background on the GTA's role.

1.1 Motivation

Following the same focus as much of the previous research on GTA-student interactions, I began studying GTAs in the classroom by looking solely at the GTAs' interactions with students. I observed similar GTA behaviors in my data as other researchers had before in theirs: mainly that GTAs often tend to explain or ask targeted questions but don't often ask students to elaborate on their thoughts and ideas or carry open conversations with students (Paul, 2012; Kyle et al., 1980; Goertzen, Scherr, & Elby, 2010a).

Some research has studied potential reasons behind GTAs' interaction patterns, and training programs have been developed to help GTAs modify and refine their interaction practices (Goertzen, 2010; Etkina, 2000). I began to think that examining the students' processes surrounding interactions, as well as the interactions themselves, would provide more understanding of the GTAs' practices. Motivated by my initial review of pilot data and some recent research on GTA-student interactions (Paul, 2012), I specifically questioned how these interactions relate to students' ongoing processes throughout the activities in which they were involved.

It is worth exploring an example here that further illustrates my motivation for this research. I present this example to demonstrate the need to further examine students' processes surrounding an interaction with their GTA as well as the GTA-student interaction itself. Doing so provides insight into how the students' processes are changed by the interaction, and thus by the GTA's teaching practices. This example is one I will return to throughout the study. It motivated me to continue examining the rest of my data through a particular lens, leading to the creation of the framework that is central to this research.

In this example, students are trying to find the initial velocity of a ball after it is tossed

directly upward. They are asked to take the ball as the only object in their system, and to apply conservation of energy to that system.⁴ At first I just examine the GTA-student interaction itself. The GTA approaches the students as they work and can see what the students have written on their large group whiteboard: $1/2mv_f^2 - 1/2mv_i^2 = 0$

The GTA begins:

GTA: Why is the work done zero?

S2: hmm?

GTA: Why is the work done zero?

S2: It's not?

S1: No. It's not zero.

S3: It won't be zero?

GTA: (GTA leaves)

The GTA begins the interaction by asking the students a probing question about their work term. This has the effect of making the students question the value of their work term and deciding almost immediately that it is incorrect. The GTA does not follow up with anything further and leaves. Examining the GTAs' question and lack of response to the students' correction, one can infer that the GTA did not actually intend for the question to be probing at all but to identify an error the students had made.

This interaction is focused on directing the students' attention to their error in setting work to zero. The interaction nudges the students to refocus on their work term without going into detail on what to do with that term. The interaction does not focus on any reasons for why students might have set it to zero, or why it should not be zero.

Just looking at the students in the interaction, only three pieces of their process stand out:

1. they have set work to zero,
2. they identify work being zero as incorrect, and

⁴Full instructions for this activity can be found in Appendix A. An explanation of physics terms specific to the setting of this study can be found in Section 3.2.2

3. S2 and S3 seem confused by that identification.

Examining the interaction, one can only glean a small part of the students' process and how it changes. Yet, their process outside of the interaction may be affected by the interaction as well. Therefore, it would be valuable to analyze how the interaction is situated in the students' process by analyzing what happens before and after the interaction. This analysis would provide a better understanding of how an interaction with a GTA relates to the students' process and thus how it helps create a more or less interactive environment.

Examining what happens after the interaction can reveal whether the interaction led to any further discussion, confusion, or progress for the students. In this example, the dialogue after the interaction proceeds with:

S2: Work equals... I can't remember the formula for work.

S1: No, work - Yeah, work is just, um, F_x times Δx plus F_y Δy plus, F_z Δz , all added together ($F_x * \Delta x + F_y * \Delta y + F_z * \Delta z = W$).

S2: Well, hold it. F_y Δy is...

S1: So using gravity

S2: Everything is zero plus F_y Δy .

S1: Gravity's only going to have the y component.

S2: Yeah. Nine point eight one times...

In this case, the students keep moving forward - almost seamlessly moving from the correction that work is not zero to the correct formula for work. The focus on correcting the error during the interaction is followed afterward by the students' continued focus on making progress toward a solution.

Though questions arose for S2 and S3 during the interaction that seem to indicate they might be confused, there is no further discussion afterward to expand on that. Nor do the students carry on any more discussion beyond what is necessary for completing the next steps.

Reviewing what the students do after the interaction reveals that the interaction led to

students smoothly switching gears and continuing a procedure but not to further reasoning about the switch.

Examining the portion of the students' process before the interaction reveals how the students came to set work to zero initially: whether the decision was shared or individual; and whether or not the students discussed their reasoning for the move. The dialogue before the interaction proceeds as follows:

S1: Change in kinetic energy equals work. Ah, work is zero, because you're- it's the surroundings... well...

S2: Well, then, how do you calculate the velocity if work is zero?

S1: 'cause your kinetic energy final equals final-K, no, it needs...

S2: So...

S1: In this scenario, um, kinetic energy's going to be one half m v squared.

S2: And work,

S1: So it's going to be your final velocity minus your initial velocity.

S3: So final velocity equals initial velocity.

S1: Then your work- Your work is either going to be your gravity calculation then, or it's going to be zero.

S3: It should be zero.

S1: Cause if you're choosing your surroundings to be, um, just the ball, you have to take into effect gravity.

S1: But if you choose to make gravity, um, you include it in your system, then it's zero, because there are no other forces acting on it.

S2: But it can't have zero in it, because zero makes everything zero.

S1: But, it doesn't necessarily, because if you chose to have the ball and gravity in your calculation, you're going to have more kinetic energy you have to calculate, so...

S3: (Writes out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard)

S1: one half m v squared final...zero.

(The GTA then approaches, looks at the whiteboard, and begins the interaction.)

There is considerable discussion of ideas before the interaction. S1 correctly determines that the work is the “gravity calculation” if the system only includes one object.⁵ S1 also determines that the work should be zero if the ball and gravity are included in the system because there would be no other forces in the surroundings. While his conceptual reasoning is correct in general, it does not fit the equation the students are using, $\Delta K = W$, which is the correct equation for this problem. S2 sees this and challenges S1. S1 responds to the challenge by incorrectly adding that the kinetic energies would be different, and so there should not be a problem. S3 decides, with reasons hidden, that work should be zero and begins writing out the energy terms for that scenario. S1 follows along, seeming to accept S3’s move.

In this example, ideas are expressed and challenges are made before a final decision is accepted and the procedure to construct a solution continues. Not only is the decision to set work to zero in error, S1’s reasoning for why it might be appropriate - that a gain in kinetic energy would make up for it - is also erroneous.

Putting together the situation before, during, and after the interaction, now offers a more complete picture of how the interaction is situated in the students’ process. The students first discuss the reasoning for different possibilities of what to do with work, and one of the ideas expressed is erroneous. A final decision is made to erroneously set work to zero. The GTA focuses on the work being zero, but does not seek out the ideas behind it. The interaction affects a change in the students’ procedure by pointing out their error. This change continues after the interaction where the students immediately switch gears by setting work to the correct term and continuing their solution. The students do not re-engage with the ideas they shared before the interaction.

I presented this example to illustrate the need for further research of students’ processes

⁵I’ve generalized S1’s reasoning to pull out what is correct in his ideas. Due to the specific language S1 uses, it is also clear that there are incorrect details within the correct general idea, but those are less relevant to this discussion.

surrounding an interaction with their GTA as well as the interaction itself. While this study will add to the body of research on GTA-student interactions in physics courses, it also holds implications for GTA professional development.

1.1.1 Implications for GTA Professional Development

By analyzing how the interaction is situated in students' processes, research may be able to inform GTA training by providing GTAs with more specific details about how their interactions work within the students' processes. Assume for a moment that the example in the previous section represents a common pattern in which students discuss their ideas about how to construct a solution, make some decision on a procedural move, are corrected by the GTA, and move on in a different direction, never returning to their previous discussion.

Just examining the GTA during the interaction, GTA training may encourage the GTA to continue asking questions to pull students' ideas out. Yet, the GTA would have to be prepared for a broad range of responses from the students. Responses might range from complete ideas coming out immediately to confusion, "I don't know's, or blank stares. It can be overwhelming for a novice teacher to prepare and attempt to respond accordingly to so broad a range of possible responses.

By looking at the entire pattern of the students' process, one can narrow the range of expected responses, knowing the students have already discussed their ideas. More targeted training might instead guide the GTA to re-ignite the students' previous discussion with each other, knowing something incorrect came out of a discussion. This would allow the GTA to step back for a moment, listen to the students repeat their ideas, and further diagnose their situation from a less vulnerable position.

Focusing on the entire process rather than just the interaction may lead to improvements in the specific guidance provided in GTA training. By creating a new framework, this study provides a tool to identify and analyze those processes.

1.2 The GTA's Role

The focus of this research is on GTAs' interactions with students. Therefore, it is helpful to understand a bit about the GTAs' situation. GTAs have multiple roles in graduate school. They are students taking classes, beginning researchers, and teaching assistants. While each of these roles is valuable to the GTAs' professional development as a physicist, advancement through graduate school is typically only dependent on their performance in the first two roles. There is generally less motivation and support for the development of graduate students as teachers than as researchers and physics content experts (Lin, 2008; Luft, Kurdziel, Roehrig, & Turner, 2004).

Physics GTAs are often novice teachers when first assigned to these roles. Typically, GTAs get some form of teacher training, but the amount and quality of the training varies (Shannon, Twale, & Moore, 1998; Luft et al., 2004). Lack of appropriate support and pedagogical training leaves GTAs unprepared to use research-supported teaching methods in their classrooms. Rather, Luft et al. (2004) found that GTAs based their teaching practice on their own intuition and assumptions that their students learn in the same way they do. They taught accordingly by giving information as clearly as possible with the expectation that students would spend significant time outside of class actively engaging with the materials. However, this is not the case everywhere, as several training programs have built in pedagogical instruction and support for GTAs' development as teachers (Etkina, 2000; Lawrenz, Heller, Keith, & Heller, 1992; Spike & Finkelstein, 2012b; Holmes, Martinuk, Ives, & Warren, 2013).

GTAs are typically assigned to teach labs and recitation sections, though in some circumstances, GTAs might teach a majority of the course (Paul, 2012) or teach alongside a professor in a course (R. J. Beichner et al., 2007). They are generally the sole instructor in a classroom during the labs or recitation sections and may hold office hours or tutoring sessions outside of these times as well.

The nature of the GTA's job implies that they will be in closer contact with smaller groups of students throughout a course than a primary course instructor might. This affords GTAs

many opportunities to influence students' learning processes through interactions. However, these opportunities may not be fully utilized due to GTAs' complex relationship with their teaching role and the surrounding circumstances of graduate school.

1.3 Research Questions

Interactions with students are one of the few teaching practices physics GTAs have the opportunity to develop and use to create a more interactive environment.⁶ This makes interactions a critical component of GTAs' teaching. In this study, I develop a framework to examine how GTA-student interactions are situated in students' processes during physics problem solving activities. This framework will focus on specific features of students' processes and their interactions with GTAs to answer the following questions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

⁶Sometimes GTAs have more control over other elements of a course, such as design of activities. But often, they do not.

Chapter 2

Review of the Literature

2.1 Introduction

This chapter provides a review of the literature on both GTA-student interactions and K-12 teacher-student interactions. Reviewing the body of literature on interactions will help inform and support the need for the proposed research. To give a more complete picture of interactions, I include literature on GTA-student interactions and teacher-student interactions in all STEM subjects, not just physics. To better clarify the selection of literature in this chapter, I first define what I mean by “interactions.” GTA-student interactions (and K-12 teacher-student interactions) are reciprocal actions or influences exchanged between a GTA and one or more students. These interactions can occur between a GTA and one student, a GTA and a small group of students, or a GTA and an entire class of students. I do not limit interactions to any one student-group size, but most of the research on GTA-student interactions is in the context of small groups.¹

I purposefully segment the body of literature on GTA-student interactions into two pieces. The first piece, Section 2.2.1, reviews research in which GTA-student interactions are examined to identify what they reveal about other elements of teaching such as TA training or

¹Much of the K-12 research on teacher-student interactions is in the context of whole class discussions.

the development of pedagogical knowledge. The second piece, Sections 2.2.2 - 2.2.4, reviews research examining the GTA-student interactions directly. Research in this second piece seeks to explore, describe, or explain the interactions as well as examine more about the students' responses to the interactions. It is in this piece that I discuss some of the missing pieces in the existing research on GTA-student interactions and what I examine in my own research. Finally, I introduce research on K-12 teacher-student interactions, Section 2.3, that informs and supports the elements of GTA-student interactions I study. I conclude by recognizing that K-12 teacher-student interactions research has more explicitly studied some elements of interactions that are missing from, but important to, GTA-student interactions research.

2.2 GTA-student Interactions

There are two primary ways GTA-student interactions are examined. There is research that examines interactions to support studies of other aspects of teaching and learning (e.g. studies on TA training). And, there is research focused on directly exploring, describing, or explaining interactions using analytical tools and supplementary data sources. I will review the literature of each of these ways separately. I refer to research of the first kind as “support” and of the second kind as “direct.” The literature is segmented in this way because it provides a clear path through the elements of interactions that are most important and clearly highlights the relevant research along that path.

2.2.1 Studies with GTA-student Interactions - Support

Classroom observations of GTA-student interactions are a source of rich data useful for exploring various aspects of GTAs' teaching. This section examines the ways GTA-student interactions are used when they are not the direct focus of the research, and what can be said about them through these studies.

Researchers have used interaction data² to better understand GTAs' beliefs about teaching (Spike & Finkelstein, 2011, 2010; Goertzen et al., 2010a) and GTAs' knowledge development for teaching (Seung & Bryan, 2009) among other things. However, possibly due to the small (but growing) amount of research that has been done on STEM GTAs, GTA-student interactions are most commonly seen in the literature as an evaluation method in TA training programs. The interactions and how they change with training provide valuable feedback on the potential effectiveness of TA training programs.

TA Training: Teaching Practices

Researchers discussed GTA-student interactions to varying degrees in studies on TA training. At the most informal level, researchers did not specifically mention GTA-student interactions at all, but mentioned that classroom observations of GTAs' teaching was done, implying that some attention was paid to GTA-student interactions (Armenti & Wheeler, 1978; Muhlestein & DeFacio, 1974).

At the next level, formal observations of GTAs teaching were mentioned, and ties were made between analyses of these observations and the level of success or effect of the training program (Allen, 1976; Lawrenz et al., 1992; Trautwein, 1999-2000; Ezrailson, 2004; Belnap, 2005; Robinson, 2000; Etkina, 2000). Most of these studies discussed the use of an observation protocol that has some categories focused on GTA-student interactions. All of these studies reported at least some positive changes observed in GTAs' interactions with students. For example, Etkina (2000) described how GTAs' interaction practices have changed: from lecturing to students, to questioning them and listening to them, as well as anticipating what difficulties they might have.³

²Some of the research that discusses interactions does not necessarily name them as such but uses the term "teaching practices." I determined that a study of teaching practices encompasses studying GTA-student interactions by looking at the categories in the observation protocols used by the researchers and noting several that are specific to GTA-student interactions. Thus, when I look for evidence in research of interactions being analyzed in some way, I am really looking for studies that employ classroom observations as a means of data collection and further analysis of teaching practices.

³Etkina (2000) also stressed how difficult it is to truly evaluate the effect of the training program itself, noting only that she saw an improvement in GTAs' practices.

The observation protocols in the studies above were too general to be used directly in my study as they only focused on interactions as a small piece of a teaching practice. However, a few items from the protocols described by Robinson (2000) and Etkina (2000) did influence my analysis. Robinson (2000) evaluated both how the GTA talked with students as well as whether the conversation included more conceptual talk or procedural talk. These were distinctions I made very explicit in my own analysis. Additionally, Etkina (2000) included items that target how GTAs talked with and listened to students. These included the use of probing questions, Socratic questions, and really hearing student responses. This helped influence the kinds of things I looked for in my own data as I developed my framework. I discuss this influence further in Section 4.1.7.

Some studies also discussed variation in the effect a training program had on how a GTA interacts with students. In a study on math GTAs, Belnap (2005) found the TA training program (which stressed interactive engagement) had a different effect on each GTA studied. One GTA spoke highly of the training, but it had no observable effect on her teaching practice. She interacted with her students mostly through lecture. Another GTA gave the training a fairly negative review but did incorporate interactive engagement techniques into her teaching practice. A third gave the training a positive review and incorporated its teachings into practice. Robinson (2000) also found a range in adoption of training techniques in her chemistry lab GTAs. She discussed the range in GTAs' final scores in their seven-week training class, stating that they reflect differences, "...primarily on the items involving interactions with students, eliciting reasoning when students ask questions, and relating chemical concepts to the procedural questions students often ask. Some GTAs gradually learned to draw out students reasoning; others continued to give the answer right away." (Robinson, 2000, p. 153).

Overall, there seemed to be positive changes occurring in GTAs' teaching practices, and these included changes in the way GTAs interact with their students. These changes seemed to relate to the GTAs' training programs, though it is difficult to definitively say that the training programs caused the changes in interactions. Deeper research into the effects of TA training

programs on teaching practice by Belnap (2005) and Ezrailson (2004) showed that training programs could have a positive effect on teaching practice but did not necessarily have that effect on every GTA.

It is helpful to note the probable link between training programs and teaching practice and the findings by researchers of positive changes in GTAs' interaction patterns. However, the studies above focused on interactions as a piece of a broader teaching practice that may also include group work structure, mobility of the GTA around the room, or design and creation of different activities. Thus, this discussion on GTA-student interactions must remain limited to what is stated above.

TA Training: Interaction Practices

A few TA training studies specifically explored whether or not a particular training program can change how the GTA interacts with students (separate from the rest of the teaching practice) (Brooks, Lewis, Lewis, & McCurdy, 1976; Pellathy, 2009; Smith et al., 1977). Brooks et al. (1976) reported mostly positive changes in GTAs' interactions with students with a method of one-on-one coaching on the topic of interactions. They showed that GTAs interested in and concerned about their teaching had a desire to create positive change in their interactions with students, and given some tools and coaching to evaluate their teaching, they were likely to try to make those changes. They also showed that less interested GTAs became more concerned when presented with evidence of their teaching practices.⁴

Pellathy (2009) researched content delivery in interactions, rather than conversational patterns. Using pre and post assessments and observations, Pellathy found that the GTAs remembered the representations of content and problem solving steps they were taught in training, but they did not use either with students in their recitation sections. That is to say, the problem solving steps and representations they did use with their students reflected those they were familiar with from before the training and were not impacted by the training, regardless of

⁴GTAs who were not concerned at all about their teaching typically had at least adequate if not excellent teaching practices already. These were rated by Flanders (1970) system of analysis.

their potential usefulness to the students. Training GTAs to use specific content tools when interacting with students was not necessarily enough to get them to do so. Other factors impact the choices a GTA makes about how to interact with students.⁵

In each of these studies, observations of GTAs interacting with their students were used to measure the possible influence of earlier training sessions. While there were some positive results, these pieces of literature highlight the difficulty in training GTAs to interact with students in specific ways or using specific tools.

In the literature on TA training and GTA-student interactions, researchers reported at least some positive results in the changes they observed in GTA-student interactions. A few studies identifying specific effects of TA training on interactions showed variable results in the ability of the training to affect a change in interaction practices.

Other Research with Interactions

Focusing now on the other ways GTA-student interactions are used in research will help complete the picture of how interactions are used to support research on teaching practices. GTA-student interactions are used to further understanding of and provide evidence for GTAs' development as teachers (Seung & Bryan, 2009; Volkman & Zgagacz, 2004). They are also used together with GTAs' beliefs about teaching to support the development of a framework of pedagogical knowledge (Spike & Finkelstein, 2011) and to support analysis of researcher perspectives of teaching behaviors (Goertzen et al., 2010a). And they are used to better understand how GTAs implement reformed courses (Bautistaa Nazan Uludag, 2014).

Seung and Bryan (2009) used GTA-student interactions to better understand how GTAs develop knowledge for their teaching practices. By studying GTAs as they taught Matter & Interactions (M&I)⁶ labs and recitation sections, they were able to describe how GTAs' knowledge for teaching evolved. GTAs reflected on their teaching experience through video observations

⁵Pellathy provided a possible reason for this in his examination of Specialized Content Knowledge (content knowledge used specifically for teaching), which he claimed GTAs may be lacking.

⁶My study is also done in the context of M&I labs. A description of the M&I curriculum can be found in Section 3.2.2.

of themselves, written reflections, and interviews. GTAs also set goals for each class that were categorized as either teaching (pedagogical), learning (content related), or curriculum (M&I) specific. The results showed that GTAs' interactions with students reflected their set goals for the class. For instance, if the GTAs' goal for the day was to get the class to systematically apply a fundamental principle⁷ to solve problems, the GTA used a systematic approach in modeling problem solving for his students and emphasized the details of that approach. In this way, GTAs' knowledge of pieces of the M&I curriculum (or physics content or pedagogy depending on the goal) came through in what they focused on during interactions with their students.

Seung and Bryan (2009) also discussed various problems the GTAs had that caused changes in the ways they interacted with students. These included elements such as time constraints, beginning with students' thoughts compared to modeling GTAs' ideas, and dealing with a traditional versus M&I approach to problems. This study showed that GTAs accessed and expressed different kinds of knowledge during interactions with students and that these expressions related to the GTAs' own goals for the class. It also showed that difficulties arising for GTAs caused shifts in their interaction patterns.

Goertzen et al. (2010a) and Spike and Finkelstein (2011) found that GTAs' beliefs about teaching and the ways GTAs interact with their students can be mutually supportive. In a case study of a GTA teaching Tutorial sections (see Tutorials in Section 2.2.2), Goertzen et al. (2010a) found that the GTA's interaction practices seemed to align well with particular beliefs the GTA had about teaching and learning. Spike and Finkelstein (2011) analyzed the GTA-student interactions as well as interviews of three GTAs teaching Tutorial sections to begin creating a framework⁸ of GTA beliefs and practices. They found that GTAs' beliefs also seemed to be well aligned with their practices in the classroom.⁹

⁷See Section 3.2.2 for a description of fundamental principles in the M&I curriculum.

⁸Due to the focus on GTA beliefs and the lack of focus on students' processes, this framework is very different from the framework developed in this dissertation.

⁹Further applications of their complete framework showed differences between beliefs and practices (Spike, 2014). This is discussed more below in the Descriptive Research part of Section 2.2.2.

In Summary

These studies that examine interactions to support other elements of teaching provide valuable insight into GTA-student interactions. They provide evidence that GTAs can change their interaction patterns with training, but that training GTAs to do so is a complex process; that GTAs draw on different kinds of knowledge for their interactions, and that their interaction patterns can change when they run into difficulties; and that GTAs' interactions seem to support their beliefs about teaching and learning. Again, the primary purpose of these studies was to learn about different elements of the GTAs' teaching. To complete the picture of research on GTA-student interactions and better understand how this study will add to that body of research, I next review the literature that studies GTA-student interactions directly.

2.2.2 Studies with GTA-student Interactions - Direct

As seen above, much research on GTAs in science courses utilizes GTA-student interactions for the purposes of gauging the success of training methods or for assessing different elements of GTAs' teaching development. Less research has been conducted on GTA-student interactions for the purpose of exploring, describing or explaining the interactions themselves. However, there is growing interest in studying GTA-student interactions in discipline-based education research, and particularly in PER, as more focused studies appear. Two main foci of direct research on GTAs' interaction behaviors are reviewed in this section: (1) descriptive studies categorizing GTAs' interaction behaviors and (2) explanatory studies providing possible explanations for those interaction behaviors.

In descriptive studies, researchers categorize interactions in order to examine patterns in them and create a picture of what the GTA-student interactions look like. Explanatory studies seek to find the reasons why GTAs interact with students in the ways that they do. These studies on GTA-student interactions took place in a variety of different settings and under different curricula.

There is limited research on the relationships between GTAs' interaction behaviors and

students' responses, and I identify the few studies that address this. Also, there is only a small amount of research connecting GTA-student interactions to subject matter content, and I highlight one study that does this explicitly. In this section, I focus first on the GTAs' interaction behaviors and second on the students' responses. The final section will bring in connections to content, detailing one study with all three elements:

- GTAs' interaction behaviors,
- students' responses, and
- connections to content.

Descriptive Research

Several studies on GTA-student interactions sought to categorize GTAs' behavior, either to analyze constructivist (student-centered) and traditional (teacher-centered) interaction behaviors or to compare GTAs' interaction behaviors to student achievement or process. Since there is little research directly focused on GTA-student interactions overall, it is helpful to examine this literature in light of its context: recitation sections, labs, or curriculum used. This allows me to draw out what is learned in these studies without applying the findings too broadly.

Tutorials

I start with a brief look at GTAs' teaching in recitation sections that use Tutorials from either the University of Washington (UW) or the University of Maryland College Park (UMD) (McDermott & Schaffer, 2002). Tutorials are worksheets that students work through in small groups in recitation sections, and they are designed to help guide students to construct conceptual physics knowledge. GTAs act as facilitators in the classroom, using Socratic dialogue with the students (Hake, 1992). Several studies in Tutorial classrooms pulled from a common data set consisting of video/audio recordings and interviews (Scherr, Russ, Bing, & Hodges, 2006; Goertzen, Scherr, & Elby, 2008, 2009, 2010b).

Most of the research on GTAs teaching Tutorial sections sought to explain their interaction behaviors (Goertzen et al., 2008, 2009, 2010b), which I cover later. However, Scherr et al.

(2006) conducted a quantitative study looking at the frequency of different kinds of initiations of interactions that occurred during the Tutorial session. Observations were made of the video data, and codes consisted of interactions initiated by GTAs, by students, or by the worksheets themselves.¹⁰ Scherr et al. (2006) found that GTAs initiated 64% of the interactions in the sessions overall, with two of eight GTAs accounting for a large portion of that result. Further analysis tentatively showed that GTAs' style, and not group characteristics, determined the interaction pattern. More surprisingly, they also found no more than one interaction in each Tutorial session was initiated by the worksheet. This finding ran counter to what they had expected from informal observations, prompting an emphasis on the necessity of systematic investigations into classroom practices to really understand what occurs. It is interesting to note these surprising findings, and I return to compare my own findings on the initiation of the interactions in Section 5.1.

Spike (2014) analyzed GTAs teaching practices and beliefs in Tutorial classrooms at the University of Colorado. He developed the TA-PIVOT (TA's Practices In & Views of Teaching) framework to analyze GTAs' teaching practices (during interactions) and beliefs and compare them to each other, to the curriculum, and across time.¹¹ Spike (2014) found that the GTAs' beliefs and practices could be described in three dimensions: Agency, Goals of Instruction, and Assessment. Agency ranged from more Teacher-centered to more Student-centered. Goals were further split into the kinds of Knowledge GTAs focused on (e.g. Procedural, Conceptual) and their Epistemological Stance (Answer-making or Sense-making). And Assessments could be either Constructive or Evaluative. Concerning GTA-student interactions, Spike (2014) found that GTAs' practices were typically more Teacher-Centered. Their Knowledge focused on Concepts, Epistemological Stance on Answer-making, and Assessment on Evaluation. These were somewhat misaligned with GTAs' beliefs. Beliefs tended at least a bit and sometimes dramatically towards more constructivist ideology. Practices were also not well-aligned with curricular ex-

¹⁰Worksheets had checkpoints that indicated a potential for interaction.

¹¹A complete description of the framework and its development can be found in Spike, 2014. This framework is very different from the one I develop in this dissertation as our research foci are quite different.

pectations.

Interactive Engagement Physics

Next I review studies of GTA interaction patterns in an interactive physics course that does not use Tutorials. These studies examined a broad range of interaction behaviors used by GTAs (West et al., 2013; Calder, 2006). In these studies, GTAs taught the interactive portion of the reformed physics course.¹² The interactive portion consisted of two, 140 minute discussion/lab sessions each week. Lecture was typically kept to less than an hour each week. During these sessions, students worked in small groups, participated in whole class discussions, and presented their work to the class. Their work included problem solving and experimental activities.

Both studies revealed a fairly wide range of interaction behaviors used by GTAs in small group and whole class settings. Calder (2006) identified that most GTAs used some consistent form of explanation or lecture when interacting with students while West et al. (2013) found more variation in GTAs' interaction behaviors. I find it most useful to examine the research from West et al. (2013), as it is the only large scale study of physics GTAs in a research-based interactive setting and is more recent than Calder (2006). West et al. (2013) developed and utilized the Real-time Instructor Observing Tool (RIOT) to categorize interaction behaviors of GTAs. RIOT allows an observer to quickly assign an instructional action to an instructor during a live classroom observation. Their participants were mostly GTAs (n=26) and a few faculty instructors (n=4) teaching the same course described above.

West et al. (2013) found wide variations in interaction practices across the 30 instructors. Even though the study was conducted on instructors in three separate CLASP courses covering different topics, these variations held among instructors teaching the same course and going through the same intensive training program. Variations in patterns of small group interactions included a wide range of time spent by different GTAs in different categories of behaviors. For instance, looking across all GTAs, the variation in percent time spent interacting with small

¹²The course is currently called the Collaborative Learning through Active Sense-making in Physics (CLASP) series.

groups of students in each category (talking at students, dialoging with students, observing students, and not interacting) was between 3% and 60%. Researchers expected interaction behaviors would exemplify a constructivist teaching philosophy and follow the guidelines laid out in training. But, with the variations in GTA behavior, unexpected patterns were also found. One pattern a few GTAs demonstrated was the excessive use of explanations despite strong guidance away from them in training. Another was the use of whole class discussion time, which some GTAs used excessively, and some used very sparingly despite specific prompts in instructor notes for when to do so.

Upon analyzing the data to find possible influences on interaction practices, they found evidence that the two strongest influences on GTAs' interaction patterns were the GTAs' personal teaching styles and the weekly topical changes in the curriculum. They found very little evidence for variations dependent on student grouping or temporal progression through the course (independent of topical changes), though some GTAs changed styles from one term to the next. Paul (2012) also provided for the possibility that the RIOT tool does not probe these variations in a way that allows one to see any differences due to groups or course progression.

These findings are interesting because they highlight the variety of interaction behaviors a GTA may use. They also provide evidence of variation in the GTAs' interaction behaviors throughout a single interaction (a temporal picture). Even though the GTAs used a common set of interaction behaviors, each GTA demonstrated a unique pattern of interactions with the students. This supports the need to look qualitatively at the data to continue exploring the interactions themselves.

RIOT is a tool validated for live observation and quantitative analysis. However, all data in my study is video recorded and intended for qualitative analysis, as explained in Chapter 3. Therefore, I could not use RIOT in its validated form for my data. That said, the spectrum of behaviors categorized with RIOT was influential to my analysis. I describe this influence

further in Section 4.1.7.¹³

Laboratory Settings

In laboratory settings, three specific ways of looking at interactions are highlighted by the research: pedagogical, affective, and procedural/content related (Kyle et al., 1980; Chini, 2012; Krystyniak & Heikkinen, 2007; Hazari, Key, & Pitre, 2003). Each provides different information about GTAs' interaction behaviors. In this section I highlight only the studies on pedagogical behaviors. The study that looked at procedure and content is reserved for the last piece of this section (Krystyniak & Heikkinen, 2007). Hazari et al. (2003) examined GTAs' affective behaviors. They compared GTAs' affective behaviors to student achievement and found no significant connection between the two. They did not compare the behaviors to students' processes, the focus of my study, so I will not detail this study on affective domain any further.

Chini (2012) focused on analyzing the intersection of GTAs' beliefs about teaching and their practices in a reformed lab course. Similarly to Spike (2014), this study found a contrast between GTAs' professed beliefs and their behaviors during interactions with students. The contrasts seemed to run both directions, however. Some GTAs describing themselves as more student-centered, acted teacher-centered and some GTAs describing themselves as teacher-centered, acted more student-centered. Chini (2012) concluded that a framework such as Spike's is necessary to better understand the complexities of beliefs and practices.

Kyle et al. (1980) performed a quantitative study on instructor¹⁴ actions in many laboratory sessions over five science disciplines, physics included. Researchers developed and used the Science Laboratory Interaction Categories (SLIC) to analyze the behaviors of laboratory instructors over 84 different observations for 30 minute segments during hands-on portions of

¹³I did some preliminary examination of my data based on the RIOT protocol to see if it was beneficial to modify, expand, and re-validate RIOT for video observations. However, I found that it was not, and I discuss this further in Section 4.1.7

¹⁴The authors mentioned these instructors as GTAs only once in their paper and did not describe them as especially different as other studies do. So, I use the word "instructor" when discussing this study to keep track of this difference.

laboratory activities.¹⁵ SLIC is a live observation tool in which researchers mark off an instructor's behavior from a list of behaviors every three seconds. Who the behavior is directed towards and that person's gender are also marked. The researchers found significant differences between course levels (introductory versus advanced) for three of the 15 instructor behavior categories. Significant differences also appeared among different science disciplines for 13 instructor behavior categories. Of particular interest is the use of Extended Thought Questions and Transmission of Information. Extended Thought Questions were being asked of the students only 0.3% of the time on average (0.5% for introductory labs), and Factual Recall Questions only 2.5% of the time on average (2.7% for introductory labs). Also significant was the amount of time spent Transmitting Information: an average of 25% of the time (30.4% for introductory labs). In looking at the disciplines in more detail, observations of physics courses showed fewer interactions, in general, for Transmitting Information, but more for Demonstrating Procedures than those for other courses. Asking questions was very infrequent in physics labs as well.

This study helps bring to light lab GTA interaction behaviors across science disciplines for one large university in the late 1970s. It is interesting in light of the previous discussion of West et al. (2013) as this study highlights more traditional methods of interacting than West et al. (2013) does. Since the GTAs in my study may use a wide range of interaction behaviors, it is helpful to have the findings from both studies. Similar to West et al. (2013) research, Kyle et al. (1980) did not touch the data qualitatively at all, something valuable to further understanding of GTA-student interactions.

I originally intended to use SLIC to identify the many specific GTA behaviors present during interactions and then review those behaviors qualitatively. However, as my analysis progressed, I found I would have to modify SLIC with the addition of categories and changes to category descriptions to better fit what I observed in my own data. SLIC continued to influence the kinds of behaviors I looked for in GTAs to establish descriptions of my own framework features, but it was no longer the most appropriate tool for the analysis of interactions in my data. I discuss

¹⁵“Hands-on” is worth mentioning as often times labs include a brief lecture portion to them. Lectures were not analyzed in this study.

this further in Section 4.1.7.

Explanatory Research

Further studies examined the possible reasons behind why GTAs exhibit certain interaction patterns (Goertzen et al., 2008, 2009, 2010b). All of these studies were done in recitation sections using the UMD Tutorials.¹⁶ Goertzen et al. (2008, 2009, 2010b) analyzed video observations and interview data using framing (Tannen, 1993) as a way to explain how GTAs make sense of what is occurring between the GTA and the student. Framing provides a means of explaining a GTA's behavior during an interaction by analyzing what the GTA understands his/her situation to be. Using framing, Goertzen et al. (2008, 2009, 2010b) showed that the GTAs' behaviors were tied to how the GTAs saw their immediate task, their buy-in to reform instruction, and their beliefs about teaching and learning.

Goertzen et al. (2008) found that one of the frames GTAs utilized when interacting with students is a focus on specific indicators in students' expressions. They listened for particular things such as the correct answer or a specific line of reasoning. Once this was expressed, the GTA's current task was finished, and the interaction ended. It should be noted that each GTA is unique and can focus on a set of indicators completely unique from other GTAs. Context also played a role, and a GTA might have focused on different indicators at different times. For example, one GTA focused on *listening for the correct numbers from the students*, and another focused on *expressions of how the students approached a problem*. This can already be seen in the example I provided in Chapter 1 as the GTA in that example leaves the group right after hearing the correction made. That GTA may be identified as *focusing on the correct approach*, and upon hearing it, the GTA's job was done and the interaction over.

Goertzen et al. (2009) and Goertzen et al. (2010b) then examined possible explanations for the observed GTA behaviors. They found that GTAs' buy-in (or lack thereof) to reformed instruction and beliefs about teaching and learning were contributing factors to specific GTA

¹⁶Goertzen et al. (2009) also used data from CU Boulder who uses Tutorials from UW.

behaviors during interactions. Goertzen et al. (2010b) discuss the interactions in terms of beliefs modified by context. The different GTAs in this study all focused on indicators. Yet they each focused on different indicators, supported by different beliefs about teaching and learning. For instance, in one interaction, a GTA is called over by students and asked if they have the correct answer. The GTA reviews their work, finds that it is partially correct, confirms their request, and corrects a piece that is not correct without asking the students to express their ideas. The GTA focuses, within this interaction, on the indicator of *correct answers*. In focusing on that indicator, he does not necessarily notice evidence showing that the group may not have a solid understanding. While he is focusing on an indicator, the GTA might consider himself in the frame of *checking the students' answer*. Beliefs that support this interpretation and behavior include wanting to support what is correct in students' answers and giving students the benefit of the doubt. Researchers found that the GTA's belief in giving students the benefit of the doubt and checking their answers showed through his focus on the correct answer while discounting other indicators of understanding (or lack of understanding). Another GTA focuses on the indicator of *instructionally targeted explanation*. This GTA does not accept certain student explanations that are not in line with the curriculum. Instead, he tries to guide students to more curriculum-appropriate explanations. However, in helping them get to the instructionally targeted explanation, he is too strict and does not accept some of the students' ideas that are very close to that explanation. In the end, he gives the students the explanation he was trying to get from them. His actions reveal that he frames the interaction as *guiding students to the targeted explanation*. This is supported by his belief that GTAs should make sure students get to the right answer. In general, this GTAs' beliefs were aligned with a more constructivist teaching philosophy. His practices went "awry here for the subtle reason that his view of what constitutes a good answer is narrow." (Goertzen et al., 2010b, p. 12)

In studying GTAs' buy-in to reformed instruction, Goertzen et al. (2009) examined GTAs teaching Tutorial sessions at both UMD and CU Boulder.¹⁷ A pertinent finding from this study

¹⁷UMD used UMD Tutorials while CU Boulder used UW Tutorials (McDermott & Schaffer, 2002).

is that the lack of GTA buy-in (seen only at UMD) to elements of the Tutorials manifested in the GTAs' interaction behaviors. Goertzen et al. (2009) elaborated on the buy-in and behavior of a GTA who, "feels a sense of responsibility toward his job and wants his students to succeed" (p. 5). In interviews, this GTA expressed discontent at students starting with everyday experiences to build physics knowledge instead of starting with scientifically accepted principles. He also expressed concern that the work was too difficult for students, and that it needed to be more mathematically based. These thoughts came out through his interactions with students as he told them to ignore certain phrases in the Tutorial; guided them through a non-Tutorial line of reasoning he considered more appropriate; and devoted time with students to emphasizing mathematical relations considered less essential by Tutorial disseminators. These details articulate that a GTA's lack of buy-in to particular elements of a curriculum can be reflected in the GTA's teaching practice through the interactions he/she has with students.

To summarize, the few studies reviewed from UMD provide evidence that the behaviors GTAs exhibit when interacting with their students are manifestations of a combination of factors at different contextual levels. These factors include how a GTA interprets his/her task at the most local level, within the interaction itself; what a GTA believes about his/her teaching job and student learning; and the GTA's level of buy-in to the curriculum. This research is interesting because it shows that the choices a GTA makes in how to interact with students are influenced by a complex background of thoughts and feelings. My own research does not focus on that background but focuses locally on the interactions and surrounding dialogue. However, focusing on the surrounding student dialogue offers new insight into how the interaction is situated in the students' processes. This is something the above research does not focus on but will be helpful to further understand the GTAs' behaviors and the context in which they are situated.

In Summary

The literature in this section of research directly studying GTA-student interactions provides evidence that GTAs display a variety of different interaction behaviors, and that each GTA

displays a relatively unique pattern of interaction behaviors. It also shows that GTAs' behaviors are influenced by multiple factors, underscoring the complexity involved in analyzing them.

This section is helpful to my own research in that it identifies different ways GTAs can interact with students. It also leaves me wanting to better understand how these GTA-student interactions relate to the students' processes. The next section offers more information on the students' side of GTA-student interactions.

2.2.3 Students' Responses

In order to truly understand whether a GTA is using more or less appropriate interaction strategies with their students, I examine how that interaction influences the students' processes - how students respond to the GTA during an interaction and after an interaction, and how that compares to before the interaction. However, few studies on GTA-student interactions explicitly follow the students. Those that do provide preliminary evidence that using more constructivist teaching approaches leads to a positive change in students' processes and higher overall achievement. This motivates me to want to know more about how GTAs' interaction behaviors relate to students' processes. This section is split into research that examines the relationship between GTAs' interaction behaviors and students' achievement on assessments and between GTAs' interaction behaviors and students' processes. Doing this allows me to focus first on further motivation for studying GTA-student interactions and second on the area of students' processes that will specifically inform my study.

Achievement

Connections between GTA interaction behaviors and student achievement provide evidence that more constructivist methods of interacting lead to higher student achievement (Koenig & Endorf, 2003; Paul, 2012). These studies employed specially designed observation protocols to check for different categories of teaching behaviors and then compared those behaviors to student scores on different tests. Koenig (2003) looked specifically for GTAs' use of Socratic

dialogue while students worked through the UW Tutorials and presented preliminary findings. Six GTAs were observed and rated several times over one term with the results showing a relationship between the use of Socratic dialogue by the GTA and student Tutorial post-test scores. Higher use of Socratic dialogue went with higher post-test scores. While this study is preliminary, it is helpful to have evidence of the benefit of a particular interaction behavior.

Paul (2012) also provided preliminary evidence connecting constructivist interaction styles with student achievement. Using a regression analysis, she compared the specific instructors (among other significant factors) to final exam scores (using GPA as a baseline) and tested for any statistical significance between section instructor and final exam scores and between specific interaction behaviors and final exam scores. She found only three instructors (of 30) had a statistically significant affect on their students' final exam scores. Further examination of each instructor showed that the one with a positive correlation with exam scores set up an environment in which his students were expected to participate and interact with each other. He facilitated whole class discussions in which students presented their work or engaged in dialogue with him. He also spent more time in small groups actively observing his students or not interacting with them,¹⁸ and his students were actively engaged with each other. Examination of an instructor from the same course with a negative correlation with exam scores showed him spending less time in whole class discussion and with less student participation. He spent much more time interacting with his students in dialogue but also did more explaining to his students. Examining the third instructor with a negative correlation with exam scores shows a similar pattern to the first instructor. However, the time spent observing was in passive rather than active observation.¹⁹ Paul hypothesizes that Passive Observing may send a different message to students than Active Observing.

Further exploratory analysis on specific categories of interaction showed that GTAs Ac-

¹⁸Active Observing and Not Interacting were separate codes in her study. Active Observing is described as, "Instructor is actively listening to individual students or groups" (Paul, 2012, p. 32).

¹⁹In contrast to Active Observing, Passive Observing is described as, "Instructor is scanning room and assessing classroom progress from afar or browsing black board work of groups for less than 10 seconds at a time" (Paul, 2012, p. 32).

tively Observing small groups correlated positively with exam scores. As expected, small group Explaining correlated negatively with exam score. Clarifying also showed significance but was dependent on course. It is hypothesized that clarifying was connected to the complexity of equipment and instructions in the different courses as well as the use of clarifying behavior by the GTA.

Koenig and Endorf (2003) and Paul (2012) give examples of GTAs having the potential to affect student achievement by the ways they interact with students. I now seek to better understand what both the GTA and students bring to those interactions and how the interactions relate to the students. I turn next to a few studies that discuss students' processes during and after GTA-student interactions.

Students' Processes

Students' processes are made of several elements including, but not limited to, their interaction behaviors, procedural moves they make in activities, and content they express. These elements are not necessarily mutually exclusive and are influenced by multiple layers of context. My research focuses on the elements themselves, and so I identify previous research that does the same. Each of the studies below examined one or more of those elements of process (Scherr, Close, & B., 2011; Irving et al., 2013; Karelina & Etkina, 2007; Lunk, 2012; Krystyniak & Heikkinen, 2007). An analysis of GTA-student interactions by Scherr et al. (2011) showed two different approaches to informal formative assessment and how a difference in interaction styles can help or hinder students opening up and discussing their ideas. Relational discourse expressed by the GTA involved showing a student the GTA accepted their ideas, empathized with their thoughts and genuinely wanted to know more. Students responded by continuing to discuss their ideas productively with the GTA. Expressions of ideological discourse involved a more presentational interaction from the GTA and more evaluative expressions towards the student. It did not genuinely welcome students to share their thoughts. Students responded to this style by continuing to discuss their ideas amongst themselves but excluding the GTA. The GTA did

not get the opportunity to learn more about their thinking.

What students share of their process is related to how the GTA interacts with them. This is similar to observations I have made in my own data in which students do not necessarily reveal critical pieces of their process to the GTA unless the GTA interacts with them in a way that allows and encourages them to do so. Again the example from Chapter 1 shows this. This affects how the GTA can help students with their process.

Irving et al. (2013) analyzed students' frames and frame shifts in the context of a weekly homework help session in which the GTA was constantly present with a single group of students, but not constantly interacting with them. Frames changed along two axes, Serious/Silly and Expansive/Narrow. Changes in frame showed some kind of change in the students' processes. Irving et al. (2013) found that the GTA negotiated most of the students' frame shifts along both axes. Students changed frames most often in response to one of a few types of questions asked by the GTA but sometimes after the GTA made a recommendation or a joking remark. This study touches on content (as well as heavily on process) in that one of the axes - Expansive/Narrow - relates to how the students talked about physics content. Talk on the Expansive end was more conceptual, implying a more generalizable discussion of physics. Talk on the Narrow end focused more on content for the purpose of working towards an answer. This research identified one of the influences GTAs may have on students' processes through their interactions with students and provides further support for continuing research in this area. It also identified a practical division in students' expressions of content by aligning those expressions along an axis spanning procedural to conceptual focus.

In a study examining the differences between two kinds of labs - one in which students design their own experiments (ISLE-Investigative Science Learning Environment (Etkina & Van Heuvelen, 2001)) and one in which they do not - different GTA interaction styles were seen to have different immediate effects on students' processes (Karelina & Etkina, 2007). Examples from their study showed that GTAs could foster continued sense-making in students' processes or end it through how they interacted with the students. Karelina and Etkina (2007) also

found a trend in non-design labs in which students often ended sessions of sense-making with questions for the GTA which the GTA answered directly. As West et al. (2013) speculated in their study, it is possible that the act of explaining to students influences students to wait for GTAs' explanations rather than continue to work through something difficult on their own. Karelina and Etkina (2007) did not look into this further, as that was not the purpose of their study. In Section 5.6.4, I revisit the possible patterns in students' processes before an interaction and the GTAs' behaviors during the interaction in my own data.

Finally, one other piece of research, while not focused wholly on GTAs, offers preliminary findings of the effect of GTA-student interactions on students' processes while working through a computer modeling activity (Lunk, 2012). Lunk analyzed the epistemic games (Tuminaro & Redish, 2007) students played while attempting to write a computer program to model a physical system. He found that interactions with the GTA related to the games students played both while in the GTA's presence and after the GTA leaves. Specifically he noted that when the GTA used leading questions and allowed the students to direct more of the dialogue, the students played a more sophisticated game during the interaction and continued that game after the GTA left. When the GTA transmitted information to the students, the students (by nature of listening to the GTA) played no game in the GTA's presence and showed evidence of playing a less sophisticated game after the GTA left. As these findings are based entirely on a systematic analysis of the students, with only a cursory review of the GTA's conversational style, little could be said about the GTA's interaction behavior. However, observations of the processes the students use during and after an interaction with the GTA provide evidence of the need to further formally examine the relationships between GTA-student interactions and the students' processes.

These studies provide a beginning look at the relationship between students' processes and GTA-student interactions. They find evidence that the way a GTA interacts with students has an effect on the students' processes. Supported by this research, my research further examines how GTA-student interactions are situated in the students' processes.

2.2.4 Sample Study Including Multiple Interaction Elements

A review of a final study on GTA-student interactions and students' processes pulls together multiple elements examined in the above sections. This study is useful in providing an example of how

- GTAs' interaction behaviors,
- students' responses, and
- connections to content and procedure

are examined together in the context of two styles of chemistry labs: traditional and inquiry (Krystyniak & Heikkinen, 2007).²⁰

Krystyniak and Heikkinen (2007) provide insight into the verbal processes GTAs and students enact as they interact through various parts of lab experiments. Six teams of 3-4 students each and three different GTAs were audio recorded to observe student-student interactions and GTA-student interactions through traditional and inquiry based chemistry labs.²¹ Their analysis identified the elements of the lab the interactions were focused on: Procedures, Data and Analysis, Observations, etc. Each category also included a sub category for chemistry concepts to delineate between when students discussed a chemistry concept in the context of another category. Frequency analyses were done for each of five labs: two traditional and three inquiry.

The researchers found that fewer interactions occurred between GTAs and students during the inquiry labs than the traditional labs. Yet, there was a more even distribution of talk among students and between students and the GTA during the inquiry labs. This indicates that students were able to use each other more and their GTA less during inquiry labs. A change in the GTAs' roles was also seen between the two kinds of labs, from a deliverer of information in the traditional labs to a facilitator in the inquiry labs. This was marked by a shift from discussions of the general mechanics of the lab to discussions of project details.

²⁰While the context of this study is a chemistry lab, there are enough commonalities of the experimental nature between chemistry and physics labs that a review of this study is useful.

²¹Due to the nature of the course, initial lab sessions were more traditional, followed by a series of inquiry lab sessions. Thus the same GTAs and students experienced both types of lab sessions.

Students' questions also changed to focus more on project details in the inquiry labs, indicating a change in their process. GTAs asked very few questions of students in either kind of lab, and students asked fewer questions of GTAs in inquiry labs than in traditional labs.

When examining interactions using chemistry concepts, a difference was seen between the two kinds of labs as well. Chemistry concepts were verbalized far less in the inquiry labs. However researchers hypothesized that this is because students were more comfortable with the concepts they were using and so did not discuss them as much as in the earlier labs. Researchers did, however, report evidence that students used higher process skills in both kinds of labs as they see some interactions focused in the categories requiring higher process skills: Data Analysis/Calculations/Conclusions and Predictions.

Krystyniak and Heikkinen (2007) research is valuable in its analysis of the students' interactions with each other and with the GTA in the two different types of lab courses. It showed how those interactions changed, and how that indicated a change in the students' self-reliance and the GTAs' roles.

It also provides insight into what can and cannot be learned about interactions through categorizing them by context and content. One can learn what the interactions focus on, and therefore what topics are being discussed most frequently and during which labs. However, one does not necessarily gain a temporal view of the data, and therefore does not know how the interactions are situated in the students' processes, but rather which features are more or less frequent in the different kinds of labs.

2.2.5 In Summary

To summarize this section on GTA-student interactions, I characterize the nature of the studies and a few findings. When I looked at studies analyzing GTA-student interactions in science courses, I found a range of qualitative studies, from exploratory to explanatory, as well as a few quantitative studies. All studies used observations of a natural setting as at least one main source of data. Other data sources included interviews, student evaluations, surveys, and

pre/post test scores.

Most studies focused on categorizations of teaching behaviors or interactions in some systematic way (Krystyniak & Heikkinen, 2007; Paul, 2012; Calder, 2006; Kyle et al., 1980; Scherr et al., 2011; Hazari et al., 2003; Koenig & Endorf, 2003). Findings from these studies help develop an understanding of the varied methods GTAs use when interacting with students (Kyle et al., 1980; Paul, 2012; Scherr et al., 2006; Calder, 2006; Koenig & Endorf, 2003). They provide ways one can begin to explain GTA behavior during interactions. (Goertzen et al., 2008, 2009, 2010b) And they provide a window into the possible influence GTAs' instructional behaviors have on student achievement and process (Koenig & Endorf, 2003; Paul, 2012; Hazari et al., 2003; Scherr et al., 2011; Lunk, 2012).

From the overview of this literature, it is clear there is interest in exploring GTA-student interactions and valuable insights to gain. However, as mentioned above, the literature on GTA-student interactions lacks a focus on how those interactions are situated in the students' processes - processes that include interaction behaviors, procedures, and content. I am left wanting to know

1. what changes in students' processes can be seen from before to after an interaction with the GTA and
2. how those changes relate to interactions with the GTA.

There is a need for systematic research that examines these elements of interactions. A qualitative analysis of these elements will provide information on interactions that can inform GTA professional development.

2.3 Teacher-Student Interactions

Considering the small amount of research on GTA-student interactions, especially the research connecting interactions to students' processes, I looked to research on K-12 teacher-student interactions in science education for more information on interactions. Caution must be taken

here, as GTAs and teachers share several differences: most notably in kinds and levels of expertise and in reasons for teaching (P. J. Mulvey & Tesfaye, 2006; P. Mulvey & Nicholson, 2012; White & Tesfaye, 2011). Their situations are different. Thus, one can not expect this literature to be a replacement for GTA-student interaction literature.

However, there are similarities between GTAs and teachers in the classroom. Both GTAs and teachers typically have to juggle multiple classroom responsibilities outside of teaching. Within the classroom, they are both looked up to as experts by their students, creating a space in which they are authority figures. For both, the moment-to-moment task of conducting class with the students involves interacting with them in appropriate ways to encourage learning. Within these interactions, both GTAs and teachers typically want to be helpful to their students. (Lau, 2010; Goertzen et al., 2010a; DeBeck & Demaree, 2011; Roth, 1995; Spike & Finkelstein, 2011). With these similarities in mind, the research on teacher-student interactions informs this study on GTA-student interactions.

Several studies include multiple elements I explore in my own research: teacher interaction behaviors and how they relate to students' responses and expressions of science content (Dillon, 1982; Mortimer & Machado, 2000; Roychoudhury & Roth, 1996; Van Zee & Minstrell, 1997; Ruiz-Primo & Furtak, 2007; Li & Demaree, 2010; Harris, Phillips, & Penuel, 2011; Roth, 1996; Hogan, Nastasi, & Pressley, 2000; Schroeder, Scott, Tolson, Huang, & Lee, 2007). Thus, by examining some of this literature I gain more insight into (1) the ways the teacher interacts with students and (2) possible connections between teacher-student interactions and students' processes. The main focus is on teacher-student interactions in K-12 science classrooms due to the quantity of research in this setting. I include research on teacher-student interactions in post-secondary classrooms where appropriate, but there are fewer studies of this kind.

Sections are organized in the same manner as Section 2.2.2 above. First, I examine the teacher-student interaction patterns that have emerged over the last few decades. Second, I focus attention on research that illuminates a connection between teacher interaction behaviors

and students' responses.²² Third, I review research that examines connections between interactions and discussions or use of science content. The literature I discuss often combines multiple elements of interest in one study. Therefore, it is helpful at the end of this section to review a study that pulls in all pieces in a bit more detail so I can examine how they might fit together. This organization allows me to best highlight teacher-student interaction behaviors, the content oriented and non-content oriented elements of students' processes and the relationships to teacher-student interactions.

2.3.1 Teacher-Student Interaction Patterns

Initiate, Respond, Evaluate (IRE)

I found it clearest to approach research on teacher-student interactions chronologically. I begin with early findings of interactions and progress through their evolution to more modern ones. An early account of research on teacher-student interactions revealed that two-thirds of classroom verbalizations were done by teachers (Flanders, 1970). Further early research led to the emergence of a specific three-point classroom interaction pattern. The teacher first "I" nitiated a question to the students. Students "R" esponded to the question, and the teacher then provided an "E" valuation or "F" eedback of the response (IRE/F) (Sinclair & Coulthard, 1975). This commonly seen triadic dialogue pattern often revealed classroom interactions in which teachers asked questions of students in order to further the agenda of the lesson but not necessarily to attend to students' ideas (Lemke, 1990). Lemke (1990) detailed the intricacies in these types of interactions, as well as variations in them - for example, teacher monologues and student questions to teachers - and how content themes are built within interactions. I will return to Lemke in Section 2.3.3.

²²Much of the research on teacher-student interactions stems from observations of teachers interacting with a whole class of students, rather than small groups. This creates a different dynamic in the interaction since keeping the attention of a large group of students requires some different tactics than with a small group (e.g. calling on different people more frequently rather than having a one-on-one multi-turn exchange). Whole class discussions are also not always in the context of students doing an activity, distinguishing it further from small group interactions. Teachers might display behaviors in whole class discussions that I do not necessarily expect to find in my own research. However, other behaviors I do anticipate observing, and so findings from these studies are still useful. Where I can, I make mention of studies that look at teacher-student interactions in small groups.

As researchers explored the IRE pattern of interactions in more detail, they found the need to elaborate on the pattern, particularly the E piece. Teachers did not always simply Evaluate students' answers and move on. Further studies showed series of complex moves made by teachers using this pattern: moves dependent on purpose and context (Nasaji & Wells, 2000; Cazden, 1988; Mortimer & Machado, 2000; Scott, Mortimer, & Aguiar, 2006). For example, the details of the Evaluation piece changed with a change in the teacher's focus from correct expressions of science concepts to elaboration of students' ideas (Mortimer & Machado, 2000; Scott et al., 2006).

Mortimer and Machado (2000) discussed the process through which a teacher helps a group of students recognize a conflict in their reasoning about a chemistry concept and then resolve that conflict. They analyzed the use of different extensions of the IRE pattern and found that the teacher used both Evaluative and Elaborative "E"s to influence the discussion in different ways. An Evaluative response from the teacher was said in a more assertive tone with questions being more closed. It was used to help students confront a mistake in their language or reasoning. An Elaborative response was spoken more calmly and involved more open questions. It invited the students to expand on their thoughts. I return to more detailed analyses of this study in the section on Students' Processes.

Branching Away from IRE

Along with an elaboration of the IRE pattern, there is a branching of research on teacher-student interactions that found the IRE pattern no longer useful (Van Zee & Minstrell, 1997; Ruiz-Primo & Furtak, 2007; Chin, 2007; Harris et al., 2011; Viiri & Saari, 2006). Instead, other interaction patterns emerged. Ruiz-Primo and Furtak (2007) found the Elicit, Student, Recognize, Use (ESRU) pattern more useful for analyzing their interactions. This pattern begins similarly to IRE as the teacher must Elicit a question, and Students then respond to the question. It diverges, however, as the teacher Recognizes the students response, and then Uses that response to continue the interaction.

Van Zee and Minstrell (1997) also moved away from the IRE pattern, finding a pattern with the student as the focus to be more helpful in exploring interactions.²³ This allowed them to examine “reflective toss,” the strategy in which a student expresses a thought, and the teacher tosses the thought right back to the student to elicit the students’ elaboration of it.

With branching away from the IRE pattern, there is quite a variation of interaction patterns that emerge, and the patterns become unique to each study. This is often the result of researchers focusing on different elements of interactions as well as using various methodologies (Lau, 2010; Roychoudhury & Roth, 1996; Hogan et al., 2000; Roth, 1996). However, as the interaction behaviors and patterns diverge, what emerges are research foci branching in several distinct directions. Thus, rather than continuing to identify the patterns themselves,²⁴ I find it more helpful to note the various foci emerging in interactions research:

- teacher attention (Lau, 2010)
- informal formative assessment (Ruiz-Primo & Furtak, 2007; Black & William, 1998)
- explanation and argumentation (Driver, Newton, & Osborne, 2000; McNeill & Pimentel, 2010)
- wait time (Rowe, 1974; Tobin, 1987).

I refer the reader to the various references for further reading on these topics.

I should also mention here that some research encompasses a bit from multiple branches by focusing more broadly on the teaching process and constructivist approach to learning through interactions. By creating a classroom in which students construct their knowledge of science, and by fitting themselves into that classroom as a shared partner in the learning experience, these teachers create unique settings in which researchers examine interactions between the

²³The IRE pattern examines talk in the order of teacher-student-teacher. Van Zee and Minstrell (1997) found student-teacher-student to be more revealing.

²⁴I will continue to mention specifics of particular interaction patterns in later sections based on their relevance to understanding those pieces of literature.

teachers and students and among students (Roychoudhury & Roth, 1996; Hogan et al., 2000; Li & Demaree, 2010; Roth, 1996).

GTAs in my study interact using different methods at different times, each creating a unique experience with the students. Therefore, I find research in multiple branches useful for my analysis. I find it helpful for understanding various teacher interaction behaviors to briefly look at one study in particular. This study is an example of a qualitative description of a teacher's interaction behaviors in an inquiry based physics lab (Roychoudhury & Roth, 1996).

Roychoudhury and Roth (1996) examined interaction patterns among students and between the teacher and student groups in an inquiry based high school level physics lab. The study looked more generally at interactions and their connection to the process of designing and executing an inquiry based physics lab. I review the teachers' interaction behaviors here and the students' in the next section.

Roychoudhury and Roth (1996) found that teacher interactions varied with different stages of the experiment. During planning and prep stages, the teacher interacted in two different ways: as a coach, and as a Socratic dialogist. The nature of these interactions depended somewhat on where the students were coming from. The teacher used Socratic dialogue more if the students already had ideas about a concept and used explaining more if the students were just being introduced to an idea. Once the students were carrying out their plans and collecting data, the teacher acted more as a research advisor toward them using combinations of questions and suggestions to help the students along with their plan. In these ways, the teacher changed the way he interacted with students dependent on context.

In Summary

This literature provides examples of various interaction patterns teachers use in the classroom: IRE, ESRU, reflective toss, etc (Sinclair & Coulthard, 1975; Ruiz-Primo & Furtak, 2007; Van Zee & Minstrell, 1997). It also provides information on how those patterns play out throughout the class or during the interaction (Mortimer & Machado, 2000; Roychoudhury & Roth, 1996).

It is particularly interesting to note a difference in this literature compared with the literature on GTA-student interactions. The literature on interaction behaviors in GTA-student interactions is focused mostly on the GTA. Researchers have not looked as much to the students to systematically analyze how they are responding.²⁵ Thus, an interaction pattern in that literature is typically a description of GTA behaviors during an interaction.

In this section, researchers examined the students as well as the teacher. Often the emphasis of the pattern is on what the teacher does, but the students “R” response in the IRE pattern and in the ES(tudent)RU pattern clearly indicates that there is some focus on what the students do during an interaction. Thus, an interaction pattern in this literature often means a temporally organized combination of teachers’ and students’ verbal moves.

This overview of interaction patterns provides insight helpful to analyzing my own observations. GTAs use questions mixed with explanations. Some of their questions are used as informal assessments of students’ knowledge and others are used to challenge students’ thinking. There are times in which GTAs pay more attention to their students’ ideas and times when they do not. This section of literature provides a base of interaction behaviors that aids analysis of my data and development of the framework. In Section 4.1.7 I discuss how the dialogue patterns influenced the development of features of my framework.

2.3.2 Students’ Responses

As mentioned previously with GTA-student interactions, I look at students’ responses to teacher-student interactions in order to truly examine the relationship between the two. As in Section 2.2.3, I separate the literature into research connecting teacher-student interactions with students’ achievement on assessments, then with students’ processes. Both of these areas lend support for the need to do further research on GTA-student interactions.

²⁵Students are looked at to provide information on the GTAs’ behavior, but not studied themselves (West et al., 2013).

Achievement

A meta-analysis of literature linking teaching behaviors to student achievement showed a positive effect of constructivist teaching methods on students' test performance (Schroeder et al., 2007). This effect was seen for question-asking strategies among other constructivist methods.²⁶ Other research also found positive relationships between specific kinds of question-based interaction patterns and student achievement. Patterns in which teachers questioned students' ideas about science and got students to elaborate on their thoughts seemed to lead to higher scores on assessments (Ruiz-Primo & Furtak, 2007; Harris et al., 2011). In one case study comparing teachers' use of content knowledge during teacher-student interactions to student achievement, researchers provided preliminary evidence that careful attention to students' confusion, scaffolding of questions without simplifying them, and deep real-life content connections may contribute to higher gains on assessments (Alonzo, Kobarg, & Seidel, 2012). Findings from these studies provide motivation for examining how these interactions operate and how they are situated in students' processes.

Students' Processes

Students' processes are examined in a number of ways, both with and without the teacher present (Roth, 1995; Van Zee & Minstrell, 1997; Mortimer & Machado, 2000; Roth, 1996; Hogan et al., 2000). For example, Roth (1995) studied interactions between himself and his students while they explored Newtonian mechanics in a micro-computing environment. Roth set up a "ball toss" scenario on the computer for his students and questioned them on three parts: first to make a prediction; second to probe real world connections; and third to clarify their terminology. Changes in students' process could easily be seen as the students moved from making an incorrect prediction, to describing correctly their observations of the motion, to connecting with three possible real world examples, and finally to selecting the appropriate physics terms to describe the computer scenario. The changes in their process were robust as

²⁶Positive effects were also found for several other strategies including collaborative learning, manipulation, and instructional technology, among others.

the students then used those terms to discuss future scenarios.

In another example, a teacher interacted with a small group of students using variations of the IRE pattern to get the students to recognize and resolve a conflict in their reasoning about density (Mortimer & Machado, 2000). In this case, as the teacher's "E" changed between Elaborative and Evaluative, students' process changed from explaining their ideas to evaluating their ideas. Positive changes in their process were seen whenever the students expressed correct ideas about density on their path to resolving their conflict. This revealed a connection between the teacher's pattern of interacting and the students' responses by showing the change in the students' process during the interaction.

Often, studies do not provide quite as much detail as the two above, but they allow one to examine the students' processes with and without the teacher present (Roychoudhury & Roth, 1996; Li & Demaree, 2010; Roth, 1996; Hogan et al., 2000). For example, Roychoudhury and Roth (1996) looked at interactions among students to see how they work together and how that relates to the lab and interactions with the teacher. Student groups in this classroom took on three different interaction styles: Symmetric, Asymmetric, and Shifting Asymmetric. These different ways of interacting related to the process students went through in conducting their experiment. For instance, during Symmetric interactions, students might Collaborate, or they might Argue. Collaboration was seen when students were developing the meaning of a concept and also had a shared understanding of each others' thoughts and language. Argumentation was a mode used to generate many ideas about a problem. Asymmetric style was most commonly used in teacher-student interactions towards the beginning of planning the experiment. These studies provide insight into the kinds of student behaviors and the processes that accompany them I see in my data of students both with and without the GTA present.

In Summary

The literature on teacher-student interactions and student achievement illuminates a positive relationship between more constructivist interactions and students' assessment scores. The litera-

ture exploring students' processes showed a strong relationship between the interaction patterns a teacher uses and the resulting students' process. This provides more support for examining GTAs' interaction behaviors by situating them in students' processes.

2.3.3 Connections to Content

Several studies discuss the construction of students' ideas about content (Mortimer & Machado, 2000; Scott et al., 2006; Van Zee & Minstrell, 1997; Roth, 1996; Högström, Ottander, & Benckert, 2010; Wickman, 2004). It is helpful to look at how discussions of content relate to interactions with the GTA. There are interesting connections between interactions and content in the areas of: making observations; resolving conflicts in reasoning; and development of ideas versus content language.

I start, however, by returning briefly to Lemke (1990) who, very directly and in detail, analyzed the construction of science content during teacher-student interactions. He described the construction of content ideas through language as the creation of thematic patterns. Analyzing the patterns and how they are constructed helps one identify differences in interpretations of pieces of content by different people. Lemke identified several common verbal techniques teachers used to build thematic patterns in interactions: contrasting and equating words or phrases, repeating patterns with slight variations in wording, and use of analogies to name a few. This was largely done in the structure of triadic dialogue (e.g. IRE/F) or some variation thereof. He found few instances of what he termed "true dialogue" (Lemke, 1990, p. 55) in which teachers ask questions they presumably do not know the answer to, getting students to verbalize and construct their own ideas rather than contribute to the teacher's ideas.

Making Observations

One way content is discussed in science courses is in the context of careful observation of physical systems. Some literature discusses how teachers interact with students to get students to make careful observations (Högström et al., 2010; Wickman, 2004; Roth, 1995). I reviewed

above, in the section on Students' Processes, how students in Roth (1995) made progress toward describing the "ball toss" scenario. Thoughts about content emerged towards the end of the scenario as students connected the simulation to the real world and then finally used physics terms - force, velocity, and gravity - to describe the scenario.²⁷

In chemistry labs observed in Högström et al. (2010), teachers worked with students to establish rules about what makes an appropriate observation. For instance, students in one class did not know initially that they were supposed to be aware of the changes a certain substance experiences in different solutions, nor did they make connections to the chemical concepts. In this case, the instructor questioned students about what they saw and probed them to elaborate their response. When she heard them finally describe differences in their observations, she made a concluding statement to them, establishing their descriptions as valid and hinting at an underlying chemistry concept. It is helpful to see how a teacher might guide students to focus on particular pieces of an experiment. This guidance might also transfer to other activities, such as demonstrations or problem solving, in which a GTA guides students to think about particular pieces of a physical mechanism or information from a problem statement.

Conflict Resolution

There are also connections to discussions of content examined in the context of students explaining their ideas and resolving conflicts in reasoning (Mortimer & Machado, 2000; Van Zee & Minstrell, 1997). I return again to Mortimer and Machado's study for an example of this. In this study a teacher helped a small group of students recognize a conflict in their reasoning on density. The teacher wanted the students to use their observations from a demonstration to create a picture of molecules of water, ice, and concrete. The students drew ice particles closer together than water particles, and the teacher attempted to get them to recognize that error.

As mentioned above, the teacher used the IRE method of interacting with the students, and

²⁷The final connection to physics terms was done in this case without any prompting from the teacher, indicating that the terms were already a stable way of describing the real world scenario. However, without the teacher prompting students to think about a real world scenario, it was unclear a connection to physics terms would have been made.

changed the “E” from Elaborative to Evaluative depending on the context of the dialogue. The students responded by changing their process from explaining their ideas to evaluating their thinking. Initially, the students had the idea that all solids are more dense than liquids and drew their picture depicting that. The teacher used an elaborative method to get the students thoughts that

- molecules of solids are packed closer together than molecules of liquids and
- objects that float are less dense than the liquid they are floating on.

When one particular student voiced this conflict in reasoning, the teacher switched into an evaluative mode with a more assertive tone in her voice to get the students to focus on that conflict. The students finally recognized that a conflict existed and began confronting these two ideas after the evaluation. Through the use of IREvaluative patterns by the teacher, the students followed a path of reasoning to resolve their conflict. They finally concluded that solids are not more dense than liquids in the case of ice and water. There was a change in conceptual ideas and a rectifying of two seemingly conflicting chemistry concepts by the use of a “special case” scenario. The teacher, though beginning in a more Elaborative mode, switched to an Evaluative mode to get students to analyze their ideas more carefully. Through this analysis the students came to change their conceptual ideas about density. This research provides an example of how a teacher might influence a change in a students’ process through the examination of content ideas. This provides evidence of what to pay attention to in verbal utterances that might accompany changes in students’ reasoning about content.

Ideas versus Language

Another feature of interactions is the difference between development of conceptual ideas about content and use of content specific language. While these do not need to be tied to teacher-student interactions, there may be instances in which students express an idea about the same physics concept either accurately using everyday language but inaccurately using physics ter-

minology, or accurately using physics terminology but inaccurately using everyday language. These expressions can hint to a GTA the robustness of a student's idea about physics content and perhaps how the GTA should continue an interaction (Harlow & Otero, 2005; Sfard, 2009). As an example, Roth (1996) examined one teacher's classroom in which an inquiry-based engineering unit had students building structures as they became familiar with the process and discourse of engineering. He found that the teacher's questions were successful at helping the students build knowledge of the process of engineering: the design of structures, the tools used and why they're used, and the testing of mechanisms for stability and strength. The teacher was also under the impression that her questions would enculturate the students into the language of engineering. However, this proved to be a much more difficult process, and her students usually guessed at the answers to questions on engineering terminology. This study reveals that probing students' understanding of concepts in their own terms is at least equally important to probing their understanding in physics terminology.

In Summary

Research in this section on Connections to Content shows that there is a relationship between the development of students' ideas about content and the teacher's interaction behaviors (Mortimer & Machado, 2000; Van Zee & Minstrell, 1997). There is also evidence that constructivist questioning interaction patterns may not be enough to rectify a disconnect between ideas about content and the use of content specific language (Roth, 1996). It is helpful to be made aware of the possibility that GTAs might pay attention only to students' ideas, only to students' language, or both. I also look for connections between GTAs' interaction behaviors and changes in expressions of physics content by students. The above studies are useful, since they show that these connections do exist and how one might look for them in interactions.

2.3.4 Sample Study Including Multiple Interaction Elements

I find it useful to bring the last three sections:

- interaction patterns,
- students' responses, and
- connections to content

together by reviewing one study that systematically analyzes elements of each of the above sections (Hogan et al., 2000).²⁸ This study examines interactions between and among two 8th grade science teachers and four small groups of students as the students developed a mental model of the particulate nature of matter. Reserachers separately analyzed teacher-student interactions and student-student interactions. This study is very different from several described above as it used mixed methods to analyze the interactions. Hogan et al. (2000) used video observations and field notes to categorize verbal interactions.

Teacher-Student Interaction Patterns

Using detailed analysis of the interactions, Hogan et al. (2000) found evidence in teacher-student interactions that teachers were mostly using Socratic dialogue to help students construct their ideas:

They formed their questions in response to students' statements, rather than according to their own pre-established agenda. They made the most of the raw material for thinking that students gave them to work with. They stayed with the same topic for several turns, prompting students to think about the issue more deeply, rather than evaluating their responses and moving on to new topics. The teachers also held together the threads of the conversation, weaving students' new statements with their

²⁸Hogan et al. (2000) does not directly discuss content, but it does systematically analyze the level of students' cognitive reasoning about content during both kinds of interactions. In this way, it provides insight into students' processes concerning content.

prior statements to help them link ideas and maintain a logical consistency. (Hogan et al., 2000, p. 29)

During teacher-student interactions, student talk consisted of over 50% of the talk time. When the teachers interacted with the students, they did not attempt to get the students to one pre-determined idea. Rather, they tried to help students develop and defend their ideas in order to help them build a mental model.

Students' Responses: Processes

It is interesting to review the differences found in teacher-student interactions compared with student-student interactions. Hogan et al. (2000) found the frequency of teacher-student interactions varied among the groups. Student groups that had the least amount of Knowledge Construction amongst themselves also had the highest frequency of teacher-student interactions.²⁹ Differences in who talked during which kinds of interactions showed that in all teacher-student interactions, at least one student remained very quiet. In student-student interactions, the groups varied on the amount of talk seen from each student.

Upon examination of the longest section of knowledge constructing interactions for each group, researchers saw a large difference in the amount of questions asked by students and by teachers. Teachers used questions as a main mode of expressing, while students asked questions very infrequently. Students did, however, ask more questions of each other without the teacher present, indicating a difference in the structure of the two kinds of interactions. The nature of the kinds of questions asked of the students by students and by teachers was also very different. Teachers asked the students questions for the purpose of probing students' ideas, while students asked each other questions about the content topic itself for the purpose of constructing a model. This is expected since the classroom roles of teacher and student, as well

²⁹Knowledge Construction, Logistical, and Off Task were the three categories of modes. I equate Knowledge Construction with a piece of students' process.

as their level of expertise, are different.³⁰

Researchers coded three main interaction categories³¹: Consensual, Responsive, and Elaborative. Consensual statements refer to acknowledgement or simple agreement statements. Students uttered these statements only half as much in interactions with the teacher than in interactions amongst themselves. This indicated that the teacher did not settle for these kinds of statements. The teacher uttered them much more, but as an indicator of listening and encouraging student talk. Responsive statements were spoken much more frequently in front of the teacher as question-answering was a common task during teacher-student interactions.

Connections to Content - Reasoning

When Hogan et al. (2000) looked at the level of reasoning displayed in interactions, they saw that in groups with less Knowledge Construction during student-student interactions, higher levels of reasoning complexity were reached with a teacher present, than without. Other groups reached higher levels of reasoning complexity without a teacher present. However, when the teacher was present for these other groups, fewer talking turns were necessary to reach a higher complexity of reasoning than when the teacher was not present. This indicates that the teacher focused the group, making the Knowledge Construction more efficient.

Of the interactions patterns, Responsive patterns were mostly coded as medium reasoning complexity. Higher levels of reasoning complexity were reached with Elaborative patterns. In an Elaborative pattern, students' statements built on one another to work through ideas. With the teacher present, students' statements built on each other or on teachers' restatements of students' expressions to elaborate an idea. Without the teacher present, students' statements were not as organized, nor as easily built on. The researchers point to the lack of a focal person (the teacher) to bring them together. This provides support for the need for more talking turns to reach higher levels of reasoning complexity without a teacher present. Either way, Elaborative

³⁰It is possible that students in my study, in addition to content-focused questions, also ask probing questions, more similar to teachers' questions, to clarify each others' ideas.

³¹Under these categories came other more detailed ones, like Questions or Conceptual Statements.

talk was the most productive form of talk for Knowledge Construction.

A detailed analysis of Hogan et al. (2000) is useful as they systematically analyzed the elements of interactions that are interesting in my own research. They are most helpful in showing some of the ways the two interaction types - teacher-student and student-student - differ; the elements of talk seen in each type; and how these elements exist within the knowledge construction component of students' processes. The researchers also provide an understanding of the kinds of interactions that lead to more complex student reasoning.

However, I am mainly interested in understanding how each interaction is situated in the students' process. To get this, I need a temporal map of the processes and interactions with the GTA, something this study does not provide. Without a temporal map I can't analyze how the various elements of the interactions fit together in the greater context of the students' processes as the students progress through an activity. Thus, along with valuable information on the two different kinds of interactions, this study further motivates my own research on GTA-student interactions.

2.3.5 In Summary

To summarize this section on teacher-student interaction literature, I discuss the nature of the research and how it supports my own research. There is a mixture of qualitative and quantitative methods used in this body of literature. There are studies that use a variety of data sources with a consistent reliance on observational data from naturalistic classroom settings. While quite a bit is learned about the different kinds of interaction patterns teachers and students use through quantitative methods (Hogan et al., 2000; Schroeder et al., 2007; Roth, 1996), qualitative studies are helpful in examining students' processes (Mortimer & Machado, 2000; Van Zee & Minstrell, 1997; Roychoudhury & Roth, 1996).

I find support in this body of literature for elements of my own research foci:

- GTA interaction behaviors and
- Students' Processes

The literature on students' achievement and processes reveals a relationship between them and teachers' interaction behaviors (Hogan et al., 2000; Mortimer & Machado, 2000; Van Zee & Minstrell, 1997; Schroeder et al., 2007; Roychoudhury & Roth, 1996). Looking explicitly at the qualitative research, one can even describe this relationship (Mortimer & Machado, 2000). Thus, this research supports the existence of a relationship and the ability to examine that relationship as well as establishing an interest in doing so.

The content-oriented element of students' processes and interactions is most explicitly analyzed during qualitative studies (as one might expect for the richness of the data). These studies seem to center around a couple specific themes: making appropriate observations and conflicts in thinking about content. While my study avoids experimental activities,³² I have found in my data that conflicts with physics content arise in students' processes and that some of these will be brought up in interactions with the GTA. This section of literature gives a more complete examination of the elements of interactions I study. This is in contrast to the literature on GTA-student interactions in which analyses of the relationship between GTA-student interactions and students' processes are less prevalent.

2.4 Conclusion and Research Questions

In the above sections I reviewed the body of literature on GTA-student interactions and teacher-student interactions. I further divided up the literature on GTA-student interactions into two distinct sections. I summarize the findings and implications of them below.

In the first section, I reviewed literature that used GTA-student interactions for the purpose of supporting other aspects of teaching and learning. There was much to learn about GTA-student interactions from this research, and I found that GTAs' interaction behaviors support their beliefs about teaching and learning (which was later complicated by further research), their development of knowledge for teaching, and the complexities of training GTAs to change their interaction behaviors.

³²See Section 3.2.4 for the activities used in my study.

The second section looked at this literature by examining the elements of

- GTAs' interaction behaviors,
- students' responses, and
- connections to content.

The strongest focus of research was on GTAs' interaction behaviors with less research on the last two. Research on GTAs' interaction behaviors showed that GTAs have uniquely varied ways of interacting, and that those are supported by multiple factors: beliefs, buy-in to curriculum, and context. The small but growing body of research on the students' side showed that how a GTA interacts with students influences students' processes and relates to student achievement. There is evidence that more constructivist teaching behaviors have a positive affect on students' processes and achievement. This section illuminates missing elements of research on GTA-student interactions, and it supports the need for a systematic examination of the relationship between GTA-student interactions and students' processes.

I turned finally to teacher-student interactions which provided a more solid background, especially for the last two foci. There was more support for the link between interactions and student achievement. Like with GTA-student interactions, a positive relationship exists between more constructivist teaching methods and student achievement. I also reviewed different interaction patterns relating to students' responses, some more constructivist than others (e.g. IRE, ESRU, reflective toss) (Lemke, 1990; Ruiz-Primo & Furtak, 2007; Van Zee & Minstrell, 1997). Qualitative studies revealed a relationship between teacher interaction behaviors and students' processes, as well as connections to content. These findings show a continued interest in studying interactions as well as a need for understanding how those interactions are situated in students' processes.

This chapter on interactions literature provides an overview of the research on GTA-student interactions and teacher-student interactions. This overview reveals that *a systematic study of the relationships between GTAs' interaction behaviors and students' processes - particularly how the behaviors are situated in those processes - is missing from the literature on GTA-student*

interactions. More about these relationships is learned from the teacher-student interactions literature. I propose to begin filling this gap in the GTA-student interactions research by designing a framework to answer the following research questions on students' processes in the context of GTA-student interactions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

Chapter 3

Methodology

To answer the research questions presented at the end of Chapter 2, I design a study to identify and describe GTA-student interactions and the students surrounding those interactions. This chapter will cover the study design and data analysis used to identify that process. Beginning with a description of qualitative research, I follow with the steps taken to collect, process, and sample data. Finally, I describe my method for data analysis.

3.1 Qualitative Research Methods

Qualitative methodologies are widely used in physics education research. Qualitative research methodologies allow physics education researchers to build descriptive and explanatory models of verbal data to further understand the complexities of teaching and learning physics (Otero & Harlow, 2009). The goal of qualitative research is a general description or explanation of the phenomena under study. This differs from quantitative research which seeks to confirm and predict through hypothesis testing. Qualitative research may sometimes go no further than generating hypotheses (Chi, 1997).

Qualitative research methods typically use natural settings and small sample sizes. Researchers do not attempt to control variables, as they seek to understand how a process unfolds naturally. Researchers often use a mixture of inductive and deductive analyses. Inductive anal-

yses help researchers extract concepts directly from their data, while deductive analyses allow researchers to apply concepts to their data and check the consistency of their data with the concepts (Otero & Harlow, 2009).

Qualitative studies do not use statistical power to generalize results as quantitative studies do. Nonetheless, they are invaluable to researchers seeking to understand the complexities of their data. The power of qualitative studies comes in the depth at which they can probe verbal data to create models of phenomena. Replication of findings can be very difficult because qualitative studies are highly contextualized. But replication is not the main goal, as qualitative research seeks mainly to describe and explain the phenomena under study.

Often, researchers use a mixture of both qualitative and quantitative methods. These methods are complementary as quantitative methods can help narrow a researcher's focus as to which data to examine qualitatively, while the qualitative analysis then provides further explanation of the phenomena that is not possible through quantitative methods. Qualitative research may also be used initially on a set of data to help a researcher derive concepts and processes from the data. Later on, these findings may form the basis for quantitative studies (Chi, 1997).

Ultimately, a researcher must seek the most appropriate method to answer the research questions be it qualitative, quantitative, or mixed. My research questions specifically ask about the nature of relationships among people through a process. This study attempts to describe the interactions between the GTA and students through close conversations and the students' process surrounding those interactions.

Given the complexities of communication within groups of people, I must choose a research method that allows me examine the details of the rich verbal data collected. The need to analyze the details of complex data will also limit the amount of data that can be reasonably analyzed. For these reasons, qualitative research methods are best suited to this study.

3.1.1 A Qualitative Approach

In qualitative research, a researcher gathers data with the purpose of trying to learn as much as possible from the data gathered. The intent is to gather data that will be as informative to the research questions as possible. This means that a qualitative researcher does not attempt to gather a random sample of data, but rather carefully selects the sources, settings and participants that provide the greatest “...opportunity to learn...” (Stake, 1994, p. 244). In the following sections, I describe my choices of setting, recruitment of participants, and methods of data collection following this intent.

It is common in qualitative studies to gather multiple sources of data. The various sources can be reinforcing, lending more validity to findings and giving strength to inferences made by the researcher. In this study I rely on recorded observations and artifacts - student work, written on whiteboards and typed into the computer - collected through those recordings. The artifacts will reinforce my findings from the students. However, there are no relevant artifacts to collect from the GTAs. Previous studies of physics GTAs combine observations with GTA interviews to elaborate and strengthen their findings (Goertzen et al., 2010b; Spike & Finkelstein, 2012a). I decided against interviewing GTAs in this study for two reasons: (1) I am not seeking to understand *why* the GTAs interact in the way they do, something interviews might be most useful for, but to simply characterize *how* they interact; and (2) interviews intended to probe *how* GTAs interact would rely on GTAs reflecting on their interaction practices and thus possibly influence their actions. This is something I want to avoid to get more unrefined observations. Therefore, I am forfeiting some inference power to avoid unduly influencing the participants.

My data analysis is based mainly on grounded theory, though there are a few bounds I’ve put in place that do not follow grounded theory as closely. After discussing data collection below, I will elaborate a bit more on the process of grounded theory and how I have used it to analyze my data.

3.2 Data Collection

3.2.1 Choosing a Setting

Data for this study is collected from the Matter and Interactions (M&I) introductory mechanics studio lab course at a large, research-intensive university. Lab courses involve high levels of interactive engagement that allow me to focus on both the students as they work through activities and the interactions a GTA has with small groups of students. The M&I course places a particular emphasis on group work and strong communication among students and between students and the GTA (Beichner, Chabay, Sherwood 2009). Also, the GTAs do not govern the structure of this course, but serve as facilitators within a set structure. A course with a set structure is better suited for this study because it allows me to focus on the interactions GTAs are having with their students without the possible variations in how the GTAs might structure their class.

Students take the M&I introductory mechanics course before the electricity and magnetism course, and often, this course is their first college physics course. I take data from the mechanics section of the course because most students in that course have not yet acclimated to the nature of the course or even to the nature of physics labs in college. Therefore, they will not necessarily carry with them as many expectations of physics GTA-student interactions as more seasoned students in the electricity and magnetism course might. I expect that students' naivete of this new environment will lead to more authentic interactions between them and their GTAs. Finally, data is also collected over multiple activities, in case variations in lab topics lead to variations in the data that are valuable to my analysis.

3.2.2 Matter & Interactions Curriculum

Matter & Interactions is an innovative introductory physics curriculum designed to engage students with a modern perspective on introductory physics. The curriculum sets itself apart from more traditional introductory physics curricula by emphasizing the introduction of 20th century

physics concepts, model construction of physical systems, and the use of a few, fundamental principles (R. W. Chabay & Sherwood, 2004). There is both a mechanics and an electricity and magnetism curriculum. I will focus here on the mechanics portion, as that is the course from which the data is collected.

The mechanics course introduces the students to modern physics concepts through its presentation of several topics including relativistic momentum, the ball and spring model of matter, quantized energy, and statistical mechanics (R. W. Chabay & Sherwood, 1999). Students engage with these topics as a natural progression from classical discussions of momentum, force, and energy. Throughout the course, students work on building and exploring models of physical systems. Some of this is done through the use of computer modeling in which students can build a visual representation of a physical system. Examples of computer modeling include gravitational interactions and Rutherford scattering.

Also unique to this course, students are presented with a small set of principles from which all introductory physics topics are introduced. The course begins almost immediately with an introduction to the Momentum Principle (Newton's 2nd Law):¹

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

Once topics and problems that utilize this principle have been thoroughly reviewed, students are introduced to the Energy Principle (Energy Conservation):

$$\Delta E_{system} = W_{surr} + \text{other energy transfers}$$

as a natural and necessary progression. The Energy Principle allows for further exploration of topics introduced under the Momentum Principle. The Energy Principle leads to discussions on the internal energy of systems and energy quantization. The Momentum Principle and Energy Principle are then used to examine multi-particle systems. Finally, the course introduces the

¹The course introduces vectors and position update before momentum, but these are brief and used mainly in the context of momentum.

Angular Momentum Principle:

$$\Delta \vec{L}_A = \vec{\tau}_{net,A} \Delta t$$

followed by an exploration of thermodynamics topics.

Throughout the course, emphasis is placed on identifying systems and surroundings. Instructors spend time addressing very consciously which objects in the physical situation will be counted in the system, and which will count as the surroundings. There are often multiple options for what objects to place in each, but further solution construction may be easier or more difficult depending on those choices.

Emphasis is also placed on identification of initial and final states of a system. Choosing initial and final states of a system involves identifying the physical properties of a system at two points in time. The set of properties identified at the first point in time marks the initial state, and the set of properties identified at the second time marked the final state. The final state is typically chosen after the surroundings have acted on the system as the intent is to understand some change the system has undergone.

3.2.3 Matter & Interactions Lab

With an overview of the goals and layout of the course in mind, I can now discuss the lab portion of the course and the context for this study. The M&I lab complements the lecture by offering students a chance to actively engage with the material in a way they don't in the lecture portion of the course. Students apply fundamental principles to situations in both experiments and more advanced written problems. Students also describe and build computational models of systems using VPython.² The lab focuses students' attention on the exploration and applicability of fundamental principles to a variety of situations (R. Beichner, Chabay, & Sherwood, 2010). The topical flow of the labs usually follows the main course very closely.

The lab is structured such that experiments are generally independent from one another, as are whiteboard problems. Over the course of one lab session, students may complete one

²<http://vpython.org/>

to three separate activities, each with its own purpose and task. Computer modeling tasks are more often dependent on each other.

Students work on lab activities in cooperative groups as described in Heller and Hollabaugh (1992). Three students are grouped together (or two or four if necessary) on every lab activity, with a classroom maximum of 24 students per lab section (and per GTA). There is a heavy emphasis on collaboration, and students are expected to work simultaneously on the same activity together. Only one set of responses is handed in per group. Groups change every three labs or so.

Within the groups, members take on the roles of either Manager, Skeptic, or Recorder each lab. Each role has a set of behaviors associated with it that help the group function together to work through the lab activities with maximum student participation in the activity. One of the first lab activities students complete is a small training in how to use the group roles to help the group function well. Roles rotate each week, so all members practice the different roles.

The lab (as well as the homework) utilizes WebAssign,³ an online homework system. There is no official lab manual, but each set of instructions is uploaded as PDF files into a WebAssign assignment, or is embedded in the WebAssign assignment. WebAssign is programmed to receive students' responses as they work through the lab activities. It gives feedback in terms of "correct" and "incorrect" whenever students submit a response to any piece of the assignment. Students can also upload files or write in free responses when requested to do so. These are automatically marked as "correct" and reviewed later by a GTA who grades them and makes any further appropriate comments.

The lab is structured such that all necessary physics information is expected to be found by the students in their books, notes, or online. No extra introductory content instruction is required from the GTA at the beginning of a lab (differing from many traditional lab courses), save for a few announcements about purpose and equipment.

Experiments require students to explore physics concepts through the use of lab equipment

³<https://webassign.net/>

and data capture. Students typically use simple set-ups and a PASCO interface with Data Studio to collect and graph data. When this system is not as useful, students use stopwatches and meter sticks or rulers combined with MS Excel to collect and graph data. Experimental activities are set up in such a way that the focus is on the fundamental principles at play. Much less emphasis is placed on error analysis (a large focus of many traditional curriculum labs), and it is only included when doing so would enhance students' experience. Experimental topics include constant force, spring force, and gravitation among others.

Whiteboard problems⁴ offer students a chance to work together on unique, difficult problems using the same concepts and principles as their homework problems. These problems are designed such that any one student might find them too difficult to solve on his/her own. However, working together in a group they can all find a solution. The problems, like the experiments, span a range of topics from collisions to interatomic spring stiffness.

Computer modeling activities allow students to build physical models that they otherwise would not be able to create due to the mathematical limitations of introductory courses. It allows them to visualize their models and more abstract concepts, and it allows them to model more complex physical systems within an introductory course (R. Chabay & Sherwood, 2008). Students' use of computer modeling in the M&I course has been addressed more extensively elsewhere (Weatherford, 2011; Lunk, 2012).

3.2.4 Data Sampling within Matter & Interactions Labs

Careful sampling within this course ensures that the appropriate data are captured and limits the total amount of data to analyze to a reasonable quantity. Data sampling includes choice of lab sections, lab tables within each section, and lab activities from which to collect data.

Sampling individual groups provides the opportunity to capture the details of each interaction, as well as the students' processes while the GTA is absent. I limit the amount of data to analyze so I can focus more fully on the richness of each piece of data.

⁴Students actually write out their ideas and solutions on large group whiteboards.

With a maximum of 24 students, or eight tables per lab section, and as many as 10 lab sections in a week, I could collect between 80 and 160 hours of data each week: over 1,400 hours for an entire semester! Even if this much data was desired, neither the technical resources nor the time to analyze that amount of data are available. With these limitations in mind, I place a few more boundaries on the sample I select.

First, I choose to sample just one table of students per GTA. This provides a more reasonable 11 hours of data to process for each GTA. The table is chosen based on the location in the room that provides a good angle for clear observations while allowing me not to interfere with the students or GTAs. A full description of this selection can be found in Appendix F

Second, I bind the sampling by only taking data from a lab later in the week for each GTA. I expect that the first lab of the week for each GTA will typically include an adjustment period as that GTA re-familiarizes himself or herself with how the students approach the particular lab activities. I would expect some variation in teaching process due simply to this adjustment period and would like to avoid that variation in the data.

Third, I limit the data to a single kind of lab activity: whiteboard problem solving. Problem solving is a ubiquitous activity across physics courses. It is not limited to book problems but can be seen in both experimental activities and computer modeling in the M&I course.⁵ Its ubiquitous nature and usefulness in a wide range of activities makes it an attractive activity to study.

In order to capture the problem solving work done by students in experimental labs, data is collected from all experimental activities as well as whiteboard problem activities. Data is not collected from computer modeling activities.⁶

When all data was collected, processed (explained more fully below), and reviewed, four lab activities remained that were used in the study. I review those activities briefly here. Full instructions for each activity can be found in Appendix A.

⁵My observation of this is based on the design of the experiment and computer modeling activities and may differ in other physics courses.

⁶In preliminary data, there was no whiteboard problem solving that could be separated entirely from the writing of a program, and so further data from this activity was not collected.

3.2.5 Selected Matter & Interactions Lab Activities

Ball Toss

In this activity, students are first asked to toss a ball in the air and measure two parameters: the time it takes the ball to complete its flight from first leaving the hand to returning, and the maximum height the ball reaches at its peak. Students take two sets of measurements. They then use their measurements to calculate the initial speed of the ball when it leaves the hand. They are instructed to do this using first the Momentum Principle, $\Delta\vec{p} = \vec{F}_{net}\Delta t$, and then the Energy Principle, $\Delta E_{system} = W_{surr} + \text{other energy transfers}$, each for the system of just the ball.

Data is selected from the portion of the activity in which students solve for the ball's initial speed using the Momentum and Energy Principles.

Young's Modulus

Students calculate various characteristics of a long brass wire in this activity. They measure the diameter of the wire and its relaxed length. Then they apply various weights to the wire and measure its stretch, taking multiple measurements each time. Students use their collected data to calculate the spring stiffness of the wire, $F = k_s\Delta L = s$, and its Young's Modulus, $Y = \frac{(F/A)}{(\Delta L/L_0)}$. Using density and molar mass values for copper and zinc, students then solve for the interatomic bond length of atoms within the wire.⁷ Their solutions are based in the ball-spring model of a solid. Finally, they use their previous answers and $A = d^2$ and $L_0 = d$ to find the interatomic stiffness of the wire:

$$Y = \frac{k_s L_0}{A} = \frac{k_{s,i} d}{d^2} = \frac{k_{s,i}}{d}$$

Data is selected from the solution construction of those five quantities students are asked

⁷This involves thinking through the process of how many atoms take up a given volume to solve for the diameter of a single atom. While this can be reduced to $d = \left(\frac{m_a}{\text{density}}\right)^{1/3}$, the authors advise against doing this as it detracts from the importance of "thinking through these physical relationships..." (R. Chabay & Sherwood, 2011, p. 143).

to find. (Note: In one case, data also includes students calculating cross-sectional area as that ended up being a notable problem for their later calculations.)

Fission

This is purely a problem solving activity in which students are given the following problem statement and information:

Figure 3.1: Fission Problem Statement includes the problem story, the story diagram (the correct order of events is c, a, b), and the first four questions asked of the students. Focus is on the last of these questions, but may take dialog and interactions concerning the first three questions as they appropriately pertain to the last question.

Fission Problem

For some isotopes of some very heavy nuclei, including nuclei of thorium, uranium, and plutonium, the nucleus will fission (split apart) when it absorbs a slow-moving neutron.

For example, uranium-233, with 92 protons and 141 neutrons, can fission when it absorbs a neutron and becomes uranium-234. The two fission fragments, called "daughter" nuclei, can be almost any two nuclei whose charges Q_1 and Q_2 add up to $92e$ (where e is the charge on a proton), and whose nucleons add up to 236 protons and neutrons (U-234, formed from U-233 plus a neutron).

One of the possible fission modes involves nearly equal fragments, palladium nuclei (Pd-117) each with electric charge $Q_1 = Q_2 = 46e$. The rest masses of the two daughter nuclei add up to less than the rest mass of the original parent nucleus. (In addition to the two main fission fragments there are typically one or more free neutrons in the final state; in your analysis make the simplifying assumption that there are no free neutrons, just two daughter nuclei.)

Objects involved in the reaction:

Nucleus	# of protons	# of neutrons	Charge	Rest Mass (atomic mass units)
U-234	92	142	$+92e$	233.99
Pd-117	46	71	$+46e$	118.393

Although in most problems you solve in this course it is adequate to use values of constants rounded to 2 or 3 significant figures, **in this problem you must keep 6 significant figures throughout your calculation.** Problems involving mass changes require many significant figures because the changes in mass are small compared to the total mass. **In this problem you must use the following values of constants, accurate to 6 significant figures:**

Constant	Value to 6 significant figures
c (speed of light).....	2.99792×10^8 m/s
e (charge of a proton).....	1.60218×10^{-19} coulomb
atomic mass unit.....	1.66054×10^{-27} kg
$\frac{1}{4\pi\epsilon_0}$	8.98755×10^9 N·m ² /C ²

Fission Problem (continued)

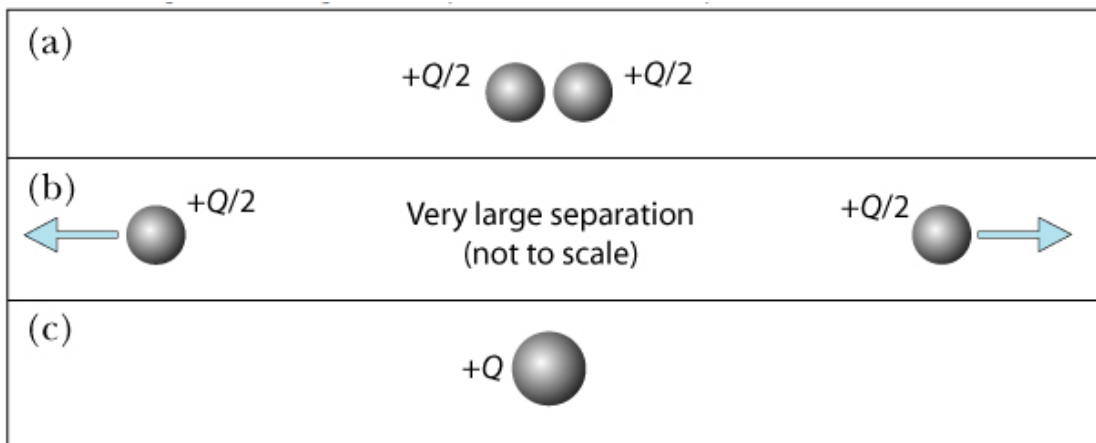
There are three states you should consider in your analysis:

- (1) The initial state of the U-234 nucleus, before it fissions.
- (2) The state just after fission, when the two palladium nuclei are close together, and momentarily at rest.
- (3) The state when the palladium nuclei are very far away from each other, traveling at high speed.

A: The final speed of the fission products

Your first task is to determine the final speed of each of the daughter nuclei in state (3), when they are far from each other.

Here is a diagram showing three important states in the process:



Fission Problem (continued)

Which diagram depicts the state of the original uranium nucleus? We'll take this state to be the initial state.

- a
- b
- c

Which diagram depicts the state when the two daughter nuclei have reached their final speeds? We'll take this state to be the final state.

- c
- b
- a

Compare the initial and final states of the system. Which quantities have changed?

- potential energy
- kinetic energy
- rest energy

What will be the total kinetic energy of the two daughter nuclei when they are very far apart?

$$K_1 + K_2 = \boxed{} \text{ joules}$$

Students first examine the problem and answer questions about the physical situation of the problem statement. They then solve for the combined final kinetic energy of the two daughter nuclei using the Energy Principle, $\Delta E_{system} = W_{surr} + \text{other energy transfers}$. Data was taken from this portion of the activity.⁸

Spectra

In this activity, students are given information about photon energies in the visible portion of the spectrum. They are then asked to find the energy jumps in Hydrogen that produce spectral lines in the visible region. Students use the Energy Principle, $E_{H,f} + K_{photon} = E_{H,i}$, to solve for the jumps. Figure 3.2 shows the problem and the table students fill in with their energy jumps and energies.

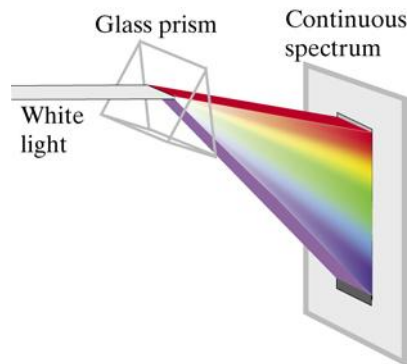
⁸Students also solved for various other quantities involved in the fission process. No data was used from these questions as there were no interactions on these questions for one of the two groups data was collected from in this lab.

Figure 3.2: Spectra problem statement

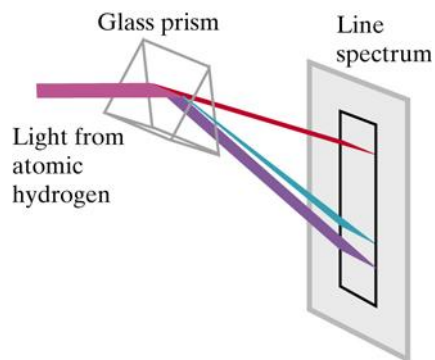
Spectra Problem 1

The average eye is sensitive to photons with energies in the range from 1.8 eV, corresponding to red light, to 3.1 eV, corresponding to violet light. White light is a mixture of all the energies in the visible region.

If you shine white light through a slit onto a glass prism, you can produce a rainbow spectrum on a screen, because the prism bends different colors of light by different amounts.



If you replace the source of white light with an electric-discharge lamp containing excited atomic hydrogen, you will see only a few lines in the spectrum, rather than a continuous rainbow.



The energies of the quantized states in atomic hydrogen are given by $E_N = -\frac{13.6}{N^2}$ eV, where $N = 1, 2, 3, \dots$

Spectra Problem 1 (continued)

Given this, predict how many lines will be seen in the visible spectrum of atomic hydrogen, and specify the atomic transitions that are responsible for these lines.

Fill in the following table, listing the energies of the visible photons emitted in order, from highest to lowest energy. Put zeroes in any remaining boxes.

N of initial state	N of final state	Photon energy
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV

Students are then asked to observe a hydrogen lamp through a diffraction grating and compare what they see to their calculated values.

Students are then asked to solve for an energy jump in Nitrogen, $\Delta E = \hbar\omega$, using information from their book as well as from a previous lab. Students use this quantity to calculate an energy jump in Nitrogen between two non-adjacent energy levels. Finally, students complete further observations of a Nitrogen lamp and compare their observations to those of Hydrogen.

Data is taken from all analytical problems in this lab. Explanations of observations are excluded as they fall within experimental activities more than problem solving activities.

3.2.6 Participants

Main Study

Participants were recruited from the 2012 Spring semester of the M&I Mechanics labs. Students enrolled in this lab were mostly first and second year engineering students. GTAs were enrolled in the physics graduate program.

GTAs were recruited in person at their first lab meeting of the semester. Students were recruited in person during the first lab of the semester. Emails were sent out to both groups about the study beforehand. Three GTAs consented to participate in the study. In each of their lab sections, almost every student consented as well.

GTAs

The GTA participants were given background surveys to identify their level of teaching experience, physics coursework experience, and comfort with each lab topic. They were also asked to rank their current priorities - classes, research, teaching - in order of importance. This survey was then given as an anonymous survey to all GTAs of all labs in the same semester. A copy of the exact survey can be found in Appendix E. I was able to compare my population of participant GTAs to the larger pool of GTAs in these areas. I found that the participant GTAs seemed representative of the population of GTAs teaching physics labs in the 2012 Spring

Table 3.1: GTA population 2012

**GTAs Background from 2012 Spring Semester
of M&I Mechanics Lab Course**

	Grad year (1-6+)	Gender (f/m)	Inter- national Student	Teaching Experience			# of yrs in physics
				M&I Mechanics (Semesters)	Other NCSU (Semesters)	Other non- NCSU	
GTA 1	3	m	y	1	0	n	7
GTA 2	1	f	y	0	1	y	10
GTA 3	2	m	n	1	2	y	6
General Population	2	-	58% y	3 semester GTA experience		66% y	7

semester. The participant GTAs' backgrounds can be seen and compared to the average GTA background in that semester in Table 3.1.

Of the three GTA participants, two had taught the M&I Mechanics lab course one other semester, and one had not. However, none were entirely new to teaching. All GTAs selected for analysis had very high comfort with every lab topic.

Students

Since almost all students participated in the study, the GTA participants were given a list of those students and instructed to only place students from that list at the observation table. GTAs then had control over who they placed at the table and how the students were rotated. In this way, I avoided selection bias of student participants.

All student participants placed at the observation table were given background surveys to identify their year and gender, their physics and math experience, and their general comfort with their current knowledge of introductory physics. The same survey was then given to all students in the M&I Mechanics course that semester. A copy of the exact survey can be found

in Appendix E. Comparing the student participants to the rest of the students in the course, I found that the population of participants placed at the observation tables were generally representative of the larger population of students in the course. Table 3.2 shows these participants compared to the averages for the course.

Table 3.2: Background information on student participants and the class population in 2012. Numbers in both rows are averages.

**Students' Background from 2012 Spring Semester of
M&I Mechanics Lab Course (% of population)**

	Gender (% m)	Year in school (% 1st)	Prior physics courses (% y)	Course comfort level (1-10, 10=very comfortable)
Participants	77	85	91	7
General Population	80	86	77	8

Previous In Vitro Study

To get a wider variety of teaching experience in the M&I Mechanics lab course, I also used data of one GTA from a previous study conducted in the 2009 Fall semester (Weatherford, 2011).⁹ I expected including this variation in teaching experience would bring a wider variety of teaching behaviors as well. The data from that period was taken during an in vitro study on students doing computer modeling activities.¹⁰ The GTA was also a member of the PER group and the PI for that study.¹¹ He was recruited through email and consented to be a participant for my study, also completing the background survey to verify his experience. The last row of Table 3.3 shows his experience added to the others.

The in vitro study was conducted in the Qualitative Educational Research Laboratory

⁹Further differences due to the nature of the different environments will be discussed in Section 3.2.7.

¹⁰There were no differences between whiteboard problem lab activities from those sections and the 2012 sections.

¹¹He did not research the activities I sampled my data from, and so was only a GTA during those activities.

Table 3.3: Background information on GTAs from 2012 (GTA 1, GTA 2, GTA 3) and Fall 2009 (GTA 4). *Gender of general population was not asked on the survey.

**GTAs Background from 2012 Spring Semester and 2009 Fall Semester
of M&I Mechanics Lab Course**

	Grad year (1-6+)	Gender (f/m)	Inter- national Student	Teaching Experience			# of yrs in physics
				M&I Mechanics (Semesters)	Other NCSU (Semesters)	Other non- NCSU	
GTA 1	3	m	y	1	0	n	7
GTA 2	1	f	y	0	1	y	10
GTA 3	2	m	n	1	2	y	6
General Population	2	-*	58% y	3 semesters total NCSU GTA experience		66% y	7
GTA 4	5	m	n	6	3	y	6

(QERL) room. The QERL room held four lab groups at one time, reducing the student population of the labs by 50%.

Students from the in vitro study did not have to be further recruited for my study as consent forms allowed me to use the data. Full recruitment procedures for that study can be found in (Weatherford, 2011). I did not attempt to identify the students to give them background surveys. However, Weatherford does mention that the gender demographics of the participant population were not representative of the larger class demographics. The participant population was 60% female and course population 45% female.

I further reviewed all four lab groups¹² in the second lab section of each week of the course for the activities of interest. I then selected one group from each section for which the number of GTA-student interactions during the activities of interest were representative of the overall frequency of interactions for that GTA. This selection left me with a gender distribution that was 42% female.

¹²The particular setting for this lab allowed space for only four groups instead of eight per section.

Pilot Study

Upon initially reviewing the data, I found that two of the three participants from the 2012 GTAs had very few interactions with their students and none during the activities I was most interested in. These data - from GTA 1 and GTA 3 in Table 3.3 - were thrown out entirely, and I decided to include data from a pilot study I conducted in the 2010 Spring semester. This data also came from the M&I Mechanics lab course but was only collected for the last four labs of the course, leaving only the Spectra lab activity to use.

GTAs and students for this study were recruited in the same manner as those of the Main study, but they were recruited much later in the semester due to the IRB process. Initially, four GTAs consented to participate in the study. All four GTAs were male international students, but no further background information was collected. In each of their labs, only three to six students consented to participate in the study, and GTAs were instructed to place those students at the observation table. It is possible that self-selection bias occurred in this sample. No background information was collected on student participants or the class, so no information is available as to how well they represent the population of students. There was one female in one of three groups; the remaining seven were male. Additionally, I found one group of students cheating through the entire lab activity of interest, so data from that sample was left out. This left data from three GTAs in one activity.

Table 3.4 shows a summary of the participants chosen, the semester in which data was taken, and the lab activities that make up the final dataset.

Table 3.4: All lab activities from which data was used for selected GTA participants in their respective years.

	Lab Activity			
	Ball Toss	Young's Modulus	Fission	Spectra
GTA 2 (SP 2012)	X	X	X	X
GTA 4 (FA 2009)	X	X	X	X
GTA 5 (SP 2010)				X
GTA 6 (SP 2010)				X
GTA 7 (SP 2010)				X

GTA Training

All training sessions were held prior to the beginning of the fall semester term. In addition to this, the first lab meeting of each semester was lengthened to include an introduction to WebAssign and to the Matter & Interactions curriculum. The basic goals and philosophy behind the course were discussed, and GTAs were given an overview of the topics and how they flowed through the course. However, due to the different semesters from which data was collected, the GTAs participated in different training sessions and weekly meetings from each other. I review these below.

Main Study

GTA 2 participated in a half-day, pre-fall-semester training session held for all first-time GTAs as well as weekly lab meetings throughout the semester. During the training, senior GTAs reviewed the role of the GTA, professional expectations, best practices for teaching,¹³ and administrative policies including grading. This was done through lecture and Q&A with a few senior GTAs. Each GTA received a copy of the GTA handbook summarizing all topics discussed during the training.

Weekly lab meetings were held throughout the semester. During lab meetings, the lead GTA would model an introduction to the lab, review any lab specific teaching practices, and review

¹³These are taken from various sources: Johnson, Johnson, and Smith (1991); Heller et al. (2007).

possible student difficulties. After this, all GTAs would do the lab activities.

In Vitro Study

GTA 4 participated in design and dissemination of multiple years of pre-fall-semester GTA training sessions. He was not a participant in the training sessions. Also, he did not attend lab meetings for the semester data was taken. In past semesters, he had attended lab meetings for the labs he taught during the study. In addition, he had extensive teaching experience both with the selected lab activities, in the M&I course in general, and outside of his role as a GTA.

Pilot Study

Due to each GTA's respective year in graduate school, I do not know which trainings, if any, GTAs 5, 6, and 7 may have attended. There are two possible trainings, both pre-fall-semester. One occurred in 2008 and the other in 2009. It is likely all GTAs attended at least one of the pre-fall-semester training sessions.

The 2008 GTA training was a single, full-day training in which GTAs were introduced to their role as GTA, professional expectations, best practices for teaching,¹⁴ and administrative policies including grading. This was done through a series of engaging activities including large and small group discussions, role play and problem solving. The 2009 GTA training was similar, but was shortened to a half-day session. After each training, GTAs were given copies of the GTA handbook summarizing the training.

Weekly lab meetings were held throughout the semester. These consisted of reviewing the lab for the upcoming week as well as reviewing how to introduce the lab. GTAs would then work through the lab activities. Additionally, a senior GTA from the PER group¹⁵ held discussions with the GTAs about particular lab activities.

¹⁴See Johnson et al. (1991); Heller et al. (2007).

¹⁵This was the same GTA from the in vitro study.

3.2.7 Video Recording and Processing

Many steps were completed between first setting up video cameras and exporting user-friendly video data. In this section I briefly review the process. A detailed account of the steps can be found in Appendix F. These steps are the same for data collected in both the 2010 Spring and 2012 Spring semesters of the lab course. I also briefly review data collection of the 2009 Fall semester course of the in vitro study.

Video Set-Up

The design of the video set-up followed Weatherford (2011) with some modifications. Two recording cameras were set up at a single lab table in the classroom. The first camera recorded video of the students and the GTA from behind - over their shoulders - capturing their actions and much of their body language but missing most facial expressions. This angle was necessary to remain unobtrusive. Figure 3.3 shows the view from this camera. A second camera was hung from the ceiling, high enough to be out of the students' way, and recorded any work the students did on their group whiteboard. Figure 3.4 shows the view from this camera. Finally, screen recording software was used to capture the work students' did on the lab computer, shown in Figure 3.5.

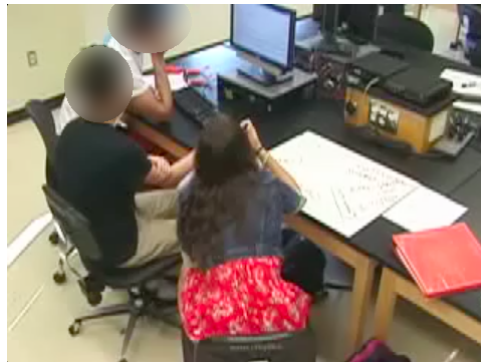


Figure 3.3: The group as captured by the over-the-shoulder camera.

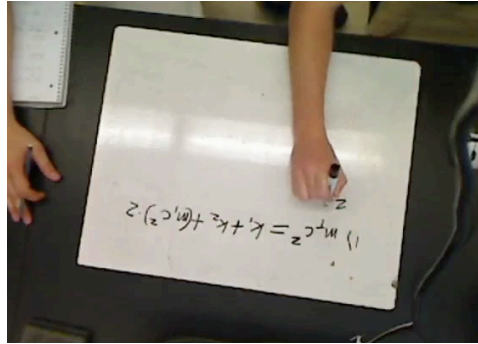


Figure 3.4: The whiteboard work as captured by the overhead camera.

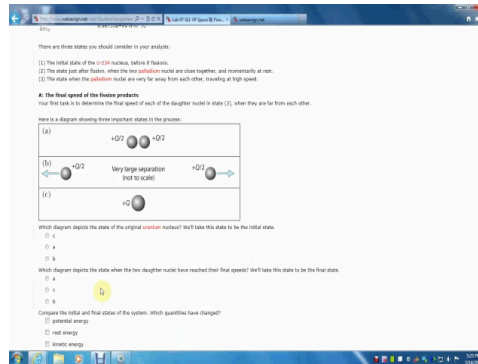


Figure 3.5: The PC work as captured by the screen capture software - BBFlashback.

In Vitro Study Video Set-Up

Data from this study was collected using the same three forms of capture as the in vivo studies (Weatherford, 2011). However, student and GTA faces were also captured with a forward facing webcam. Figure 3.6 shows view from the webcam. A Logitech webcam was also placed in an upper corner of the room to capture a whole class perspective. Data from that angle is used for one lab when the face capture webcam failed. Figure 3.7 shows the view from that camera.



Figure 3.6: The group as captured by the webcam.



Figure 3.7: The entire class gathered in the in vitro study. This was used only if the face capture failed. The group observed in this image is the one at the bottom, closest to the camera.

Video Processing

Each camera produced a separate video file with differing file types. The goal of processing the files was to create one video containing all relevant video data from all three sources for each individual lab. This process involved first converting the video files into the same format and was done using both Handbrake¹⁶ and Quicktime Pro software. The new videos were then synced to a single start time.

Once the videos were synced, they were imported to Final Cut Pro (FCP) for further processing. The PC screen videos and overhead whiteboard videos were spliced together to reflect the location of students' actions. The final video from this step switched between views of the screen and the whiteboard depending on their relevance.

Finally, the over-the-shoulder video was combined with this new combo video by playing them simultaneously as Quicktime Pro's screen capture software re-recorded them. This step completed the video processing, resulting in the final raw data files. Figure 3.8 and Figure 3.9 provide images of the final processed data files for both the main data and the in vitro study data.

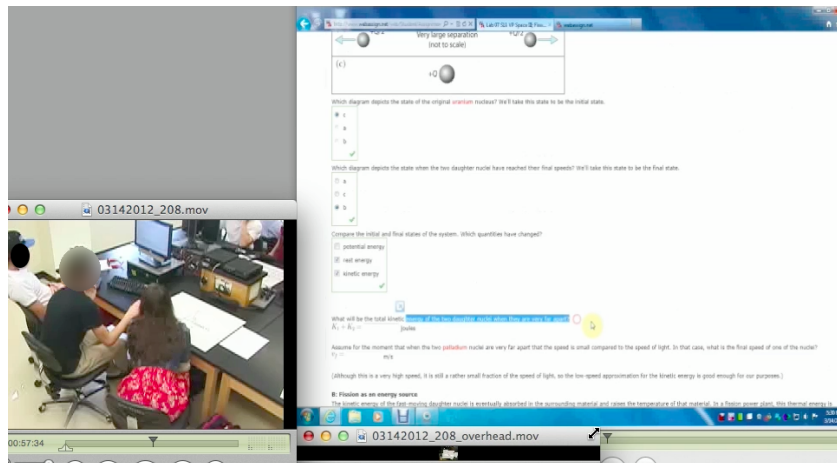


Figure 3.8: Final video after processing was completed.

¹⁶<http://www.handbrake.fr/>

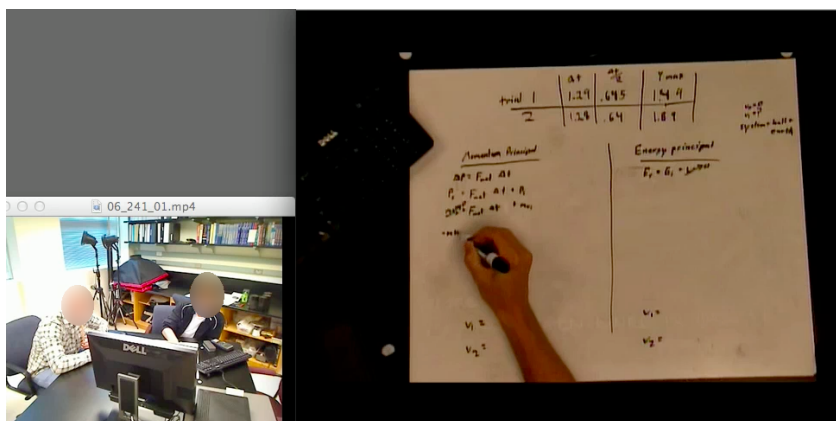


Figure 3.9: Final video from the in vitro data after processing was completed.

Problems with Video Recording

I encountered multiple difficulties with the data collection that led to a loss of video data from at least one perspective in multiple labs. These difficulties and the affected data are discussed extensively in Appendix F. When all perspectives could not be viewed for analysis, extra care was taken to build interpretations of students' actions and expressions. For instance, in one video in which the overhead camera failed, a student is identified as drawing an energy level diagram by noting that he is holding a marker and making straight, sweeping motions across the whiteboard at measured intervals. By carefully piecing together actions and expressions that *were* observable, further interpretations could be made as to the actual actions students were taking in many cases.

3.3 Partitioning the GTA-Student Interactions

Since the research questions of this study ask about specific times surrounding GTA-student interactions, the first step in reviewing the videos was to isolate those interactions. Using methods described by Scherr (2009), another researcher and I watched various pieces of videos during the times surrounding when GTA-student interactions began and ended. We then separately recorded the behaviors that seemed to mark the end of an interaction to us and the times those

behaviors occurred. We met and discussed our findings, came up with a set of behaviors defining the beginning and end of interactions, and then tested out our decisions on more videos. In this way, we collaboratively created the defining behaviors for when a GTA-student interaction begins and ends and successfully identified the beginning and end times using observations of those behaviors to within five seconds of each other. The behaviors we agreed upon are:

- Beginning a GTA-student interaction
 - The GTA begins speaking to the students, usually but not always, after watching them or listening to them work.
 - Students begin speaking to the GTA, *and* the GTA approaches them. (Students may begin speaking to the GTA before he/she is in the camera frame.)
- Ending a GTA-student interaction
 - GTA finishes speaking and walks away.
 - GTA finishes speaking, may have already been walking away.
 - Students finish speaking to the GTA - GTA may or may not have already just walked away.
 - GTA and students stop speaking to each other, and the GTA steps back or disengages from the students but does not walk away at that moment. For this to count, the GTA must eventually walk away without re-engaging or being re-engaged by the students.

3.4 Transcription

Before I could deeply analyze the data, I needed to transcribe it. I transcribed all student conversation within a group, as well as between the students and the GTA for each problem. I did not transcribe any conversations between different lab groups. All selections were transcribed into an Excel spreadsheet using the column format as described in Otero and Harlow (2009).

However, instead of dividing the transcription into talking turns or topical units, I segmented it into one-second intervals. Segmenting in this way allowed me to easily measure the amount of time spent talking by various students and GTAs. While, in the end, I did not utilize this feature in my analysis as much as I expected, I found it to be a very helpful way to visualize the true time spent throughout the problem. The amount of time spent in silences, calculations or searching for information, and talking were very apparent in these transcriptions. The three column, one-second segmentation also made the flow of the problem as well as each student's and the GTA's contributions easier to navigate. A sample of the transcription can be seen in Figure 3.10.

Even in the three column, one-second format, I did not create detailed transcriptions, as is recommended in (Otero & Harlow, 2009). I created a rough transcription with the intent to treat the transcription as a tool to guide me through analyzing the video, rather than the primary source for analysis. Thus, my transcription included the words said, some clarifying punctuation, and identifications of gestures or other movements. I used the transcription to get a sense of what students were doing and expressing at various times, and then I used the video to further examine the richness of their behaviors and expressions.

AE134					
	A	C	D	E	F
1	Transcription				
2					
3	Time	S1	S2	S3	TA
133	0:13:27		(writing $v_f = v_i +$)		
134	0:13:28		(writing $v_f = v_i +$)		
135	0:13:29		(writing $v_f = v_i +$)		
136	0:13:30				
137	0:13:31		what the hell is Fnet? (mouse)		
138	0:13:32		(mouse)		
139	0:13:33	mimm gravity	(mouse)		
140	0:13:34		(mouse)		
141	0:13:35		(mouse)		
142	0:13:36		(mouse)		
143	0:13:37		(mouse)		
144	0:13:38	but what's the mass of the ball?	okay		
145	0:13:39				
146	0:13:40				
147	0:13:41				
148	0:13:42				
149	0:13:43			doesn't matter it cancels (erases v_i)	
150	0:13:44				
151	0:13:45		(writes 0 after erasing v_i)		
152	0:13:46				
153	0:13:47		(writes +g deltat)		
154	0:13:48		(writes +g deltat)		
155	0:13:49		(writes +g deltat)		
156	0:13:50				
157	0:13:51				
158	0:13:52		(writes =)		
159	0:13:53				
160	0:13:54				
161	0:13:55				
162	0:13:56				
163	0:13:57				
164	0:13:58		do we nee- do we need the mass of the ball? (gesture)		
165	0:13:59				
166	0:14:00				no
167	0:14:01		you sure?		
168	0:14:02				yes
169	0:14:03				
170	0:14:04				
171	0:14:05		(erases v_f)	or would F net be zero?	
172	0:14:06		(erases v_f)		
173	0:14:07				no
174	0:14:08				what goes on the left side? (pointing)
175	0:14:09		this		
176	0:14:10		was		
177	0:14:11		ah is momentum principle		
178	0:14:12		so		yes (pointing)
179	0:14:13		it was		
180	0:14:14		uh (writing $m v_i =$		

Figure 3.10: A sample of transcription. Each actor is listed along the top. Cells with expressions or actions in them are colored blue along with containing text. The gray region marks the interaction with the GTA.

3.5 Data Segmentation

Data segmentation is the process of dividing the data into chunks appropriate for analysis. This allows me to focus my efforts on an appropriate grain size to answer the research questions. Data segmentation is not entirely separate from analysis, though. Data segments were created based on topics discussed in GTA-student interactions. Thus, I had to spend some time analyzing the data to understand appropriate places to segment. However, further analysis that led to the creation of the framework used to answer my research questions occurred only on the segmented data. Below, I describe the process I used to divide the data into those segments.

3.5.1 Data Segmentation Process

Data segmentation began with a review of the GTA-student interactions occurring throughout an entire problem the students were working through. I familiarized myself with the various topics brought up during the interactions, and then reviewed the data outside those interactions to become familiar with how the students dealt with those topics outside of interactions. I noticed that almost all GTA-student interactions focused on a procedural move in the problem or a conceptual idea that the students were either uncertain about or had incorrect (see Section 4.1). I decided to further explore how these topics came about and what the students did concerning them after an interaction was over. Thus, data segmentation was guided by the topics of issues that were brought up during GTA-student interactions.

The process of segmenting by these topics can be a bit complicated, so I will take an example from one of the lab activities. This problem is from the Ball Toss lab. Students are asked to find the initial velocity of the ball when it first leaves the hand using the Energy Principle for the system of just the ball. The complete problem can be found in Appendix A. First, I identify a topic brought up during a GTA-student interaction. The transcript from the interaction can be seen in Table 3.5:

Table 3.5: Sample Transcript: GTA-Student Interaction

Time	S1	S2	S3	GTA
0:18:57				Why is the work done
0:18:58				zero?
0:18:59		hmm?		Why is
0:19:00				the work done
				zero?
0:19:01		It's not?		
0:19:02	no			
0:19:03	It's not zero			
0:19:04			It won't be zero?	

In this interaction, the topic of work, and especially $W = 0$ is the focus of this interaction.¹⁷ Since work is the only topic brought up in the interaction, I then look to all dialogue before the interaction to identify where the topic of work is discussed.

In some problems, a topic may be brought up and discussed for short periods of time multiple times throughout an interaction. This would require me to pull out various chunks of dialogue separated in time. In other problems, a topic is brought up and discussed only once before the interaction occurs. That is the case with this example. As such, I will first identify when the students begin talking about work to mark when the data segment on the topic of work begins. The transcript shown in Table 3.6 occurs before the interaction.

¹⁷In some interactions, multiple topics are brought up, and I look at each one in turn. In this one, only one topic is brought up, so I focus only on that one.

Table 3.6: Sample Transcript: Before the GTA-student interaction, students only

Time	S1	S2	S3	GTA
0:16:26		and there is the (typing)		
0:16:27		separation (typing)		
0:16:28		distance, yeah (typing)		
0:16:29		(typing)		
0:16:30	oh dammit	(mouse)		
0:16:31	puts the rest of them off	(mouse)		
0:16:32		(mouse)		
0:16:33		no it doesn't (mouse)		
0:16:34	oh	(mouse)		
0:16:35				
0:16:36	we didn't have any height			
0:16:37	in that calculation			
0:16:38		oh yeah, yeah (mouse)		
0:16:39		energy principle		
0:16:40				
0:16:41		what was the		
0:16:42		energy principle?		
0:16:43	it's ah			
0:16:44	E		delta-delta K over	
0:16:45				
0:16:46	I got you			
0:16:47				
0:16:48	kinetic energy, change			
0:16:49	in kinetic energy equals work			
0:16:50				
0:16:51	ah	(writing)		
0:16:52	work is zero	(writing)		
0:16:53		(writing)		
0:16:54	because you're	(writing)		
0:16:55	it's the surroundings			

The students begin talking about work when S1 says “Change in kinetic energy equals work” at 0:16:49. Thus, the data segment begins at that point and excludes everything above it.

Next, I identify when the students stop talking about work. If they leave the topic of work before the interaction begins, I do not include any dialogue between that ending and the beginning of the interaction. However, if work is the last thing students discuss before it is brought up in the interaction, I include all dialogue through the interaction. The transcript surrounding the beginning of the interaction can be seen in Table 3.7.

Table 3.7: Sample Transcript: Beginning the GTA-student interaction

Time	S1	S2	S3	GTA
0:18:44		(mouse)	(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:45		(mouse)	(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:46		(mouse)	(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:47			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:48			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:49			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:50			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:51			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:52			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:53	zero		(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:54			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:55			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:56			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:57				why is the work done zero?
0:18:58				zero?
0:18:59		hmm?		why is the work done zero?
0:19:00				
0:19:01		it's not?		
0:19:02	no			

As the dialogue shows, work is dealt with in writing up until the beginning of the interaction, so all transcription beginning at 0:16:49 and continuing until the interaction begins at 0:18:57 is included.

Finally, I identify if and how work is discussed after the interaction. The transcript after

the interaction is shown in Table 3.8.

Table 3.8: Sample Transcript: Ending the GTA-student interaction

Time	S1	S2	S3	GTA
0:19:03	it's not zero			
0:19:04			It won't be zero?	
0:19:05				
0:19:06				
0:19:07		work		
0:19:08		equals		
0:19:09				
0:19:10				
0:19:11				
0:19:12		I can't remember		
0:19:13		the formula for work		
		(mouse)		
0:19:14	no, work	(mouse)		
0:19:15	yeah, work is just	(mouse)		
0:19:16	um	(mouse)		
0:19:17	F x	(mouse)		
0:19:18	times	(mouse)		
0:19:19	delta x	(mouse)		
0:19:20	plus F y delta y	(mouse)		
0:19:21	plus	(mouse)		
0:19:22		(mouse)		
0:19:23	F z	(mouse)		
0:19:24	delta z	(mouse)		
0:19:25		(mouse)		
0:19:26	all added together	(mouse)		
0:19:27		well Fz		
0:19:28		hold it		
0:19:29		F y delta y		
0:19:30		is		
0:19:31				
0:19:32	so using (undetectable)	zero		
0:19:33		plus F y delta y		
0:19:34		plus		
0:19:35				
0:19:36	gravity's only going to have the y			
0:19:37	component	yeah		
0:19:38				
0:19:39	so	nine point eight one		
0:19:40		times		

Work is discussed as the students identify the formula for it and continue solving the problem. The students then continue filling in the details of their equations, but do not further discuss the main topic of work in the way they have before and during the interaction. Nor do they return to discuss it at all later on. Thus, I end the data segment after they have solidified their formula for work at 0:19:34.

Two notes on segmentation are important to address here:

1. If a topic is not discussed further but students are still working on the problem, I include at least five seconds worth of action or dialogue to demonstrate that students are no longer on the topic of interest.
2. If students fully complete solving a problem during an interaction, I include no transcription from after the interaction in the data segment.

The final data segment will include the transcription found above the interaction, all transcription from the interaction itself,¹⁸ and the appropriate transcription following the interaction. The final data segment is quite long, and so I present a condensed version, with ellipses denoting excluded dialogue, in Table 3.9.

¹⁸All transcription during the interaction, regardless of topic, is included in a data segment. Transcription of other topics during the interaction remains unhighlighted and serves as context only.

Table 3.9: Sample Transcript: Complete condensed version

Time	S1	S2	S3	GTA
0:16:47				
0:16:48	kinetic energy, change			
0:16:49	in kinetic energy equals work			
0:16:50				
0:16:51	ah	(writing)		
0:16:52	work is zero	(writing)		
0:16:53		(writing)		
...
0:18:54			(writing $1/2 mv^2$ $= 1/2 mv^2$)	
0:18:55			(writing $1/2 mv^2$ $= 1/2 mv^2$)	
0:18:56			(writing $1/2 mv^2$ $= 1/2 mv^2$)	
0:18:57				why is the work done
0:18:58				zero?
0:18:59		hmm?		why is
0:19:00				the work done zero?
0:19:01		it's not?		
0:19:02	no			
0:19:03	it's not zero			
0:19:04			It won't be zero?	
0:19:05				
0:19:06				
0:19:07		work		
...
0:19:31				
0:19:32	so using (undetectable)	zero		
0:19:33		plus $F y \Delta y$		

Due to the temporal layout of the research questions, I analyze this segment by focusing more intently on each temporal section - before, during, and after - independently. However, the other sections inform my analysis as well, and so the final data segment includes all three

time periods.

3.6 Method of Analysis

Once the data was segmented, I began the deeper analysis.¹⁹ My data analysis is based on grounded theory (Corbin & Strauss, 2008). In the next section I will review the process of grounded theory. I do this here, instead of in the literature review of Chapter 2 because this literature pertains specifically to the methodology of this study, rather than the background of the research topic. Then, I will discuss more specifics of how I used this methodology to analyze my data. In Chapter 4, I follow this analysis through the creation of a framework that allows me to answer my research questions.

3.6.1 Grounded Theory

Grounded theory is the methodology by which theory is constructed from data. It is “grounded” in the data itself. Grounded theory is most useful when existing theories do not seem to sufficiently explain the data to answer research questions. By creating a theory emergent in the data, the complexity of the data can be accounted for in the theory. In grounded theory, researchers analyze data to find emergent concepts that become the basis for a theory. These concepts form the language the researcher will use to describe and explain the phenomena being studied. In this section, I will briefly review the process of the grounded theory methodology (Corbin & Strauss, 2008).

Grounded theory begins with the assumption that a researcher has identified the problem to research and has at least some data from an appropriate population to analyze.²⁰ Analysis begins with open coding. Open coding is often done in a brainstorming fashion of taking notes on

¹⁹Not all data was processed or segmented when I began analysis. I began with a smaller sample of data and continued sampling as I progressed through analysis.

²⁰Corbin and Strauss recommend beginning analysis as soon as the first piece of data has been collected so that the process of analysis guides the data collection and sampling as well as the continued analysis of accumulated data. They are also careful to mention that one can still use grounded theory methodology if one has already collected all data, as was the case in this study. This process then applies more to the sampling of data from that collection, than to the collection itself.

pieces of data. The data are broken into manageable chunks to be analyzed, and the researcher begins attempting to understand the data through describing what the data tells.

There are a variety of analytic tools available for this process. The analytic tools help sensitize the researchers to the data, allowing them to describe the data from different perspectives and at varying depths. They also help the researcher eventually pull concepts from the data that will later be used to construct the theory. A few of the tools that I have used in this study include:

- Asking Questions - Questions are asked about the participants and their situations to identify what they are doing, how they are interacting, and what they might do and how they might interact differently if a situation changed. Questions help the researcher become more sensitized to the data, as well as guide the development of concepts.
- Drawing on Personal Experience - Personal experience is a tool that allows a researcher to better identify the descriptions of concepts seen in the data. It does so by allowing researchers to compare their experiences, and how they would describe those experiences to those situations shown in the data. Personal experiences are never used to identify the concepts themselves, only to create more refined and thicker descriptions of those concepts.
- Looking at Language and Emotion - Focusing on the use of particular words and phrases helps the researcher identify various concepts that might be attached to those words. For example, the use of “I’m not sure” and “I don’t know” by students indicates a sense of uncertainty in their ideas or actions.

Analytic tools guide the analysis through the emergence of concepts. Concepts are the specific macro and micro themes that apply to the data - the categories under which the various pieces of data fit. Concepts can be more all encompassing of the chunks of data, or descriptors of some element of a chunk of data. The framework constructed in this study is centered around a major concept with mid-level and minor concepts being pulled together to

describe a process under the major concept.

The process of identifying and describing concepts is done through constant comparative analysis. Once concepts have been pulled out of one piece of data, a researcher moves on to another piece of data. The next piece is analyzed in comparison to the first piece to see which concepts are present, whether new ones emerge, and whether the descriptions of the concepts need to be refined. Analysis of each piece of data continues in this way, constantly being compared to the previous pieces, until conceptual saturation is met. Conceptual saturation occurs when each concept has been sufficiently explored and described. While this analysis could go on forever, the researcher must judge when a concept has been sufficiently described such that any addition of new data would not add much more to the description of a concept.

During analysis, researchers doing grounded theory focus on the context of and processes in the data. The context is the environment in which the study is situated. Taking into account context involves examining the conditions surrounding the immediate phenomena being analyzed that may also influence those phenomena. The context involves both micro and macro conditions. In this study of interactions among students and GTAs, the micro conditions are those of the classroom environment and assignments in which the students are engaging. The macro conditions include the possible influences of the physics course as whole, the graduate physics program, and the university system among others.

Process is the flow of actions, decisions and interactions that occur in response to the context and variations in context. Processes can be routine or disordered sequences of events. They can be visible to the researcher through a participants' actions and expressions, or they can remain hidden with evidence revealing their existence but no further details. Processes that arise in the study of GTA-student interactions may include question-response conversation or students correcting a mistake. Analyzing data for process and context helps the researcher build a more complete picture of the phenomena being studied.

The final step in grounded theory is building the actual theory through integration. Integration is the act of bringing together the concepts to explain the phenomena being studied.

In integration, a researcher identifies a main category and links other categories and concepts around that main category, filling in the details of the theoretical construct. In this phase, not every piece of data will fit the theoretical construct exactly, and there will be some pieces of data that vary quite a bit from the theory. The goal of building the theory is to create a plausible, explanatory framework for the phenomena under study.

3.6.2 Use of Grounded Theory and Methodological Variations

I began using grounded theory with a sample of a few different problems spanning three different GTAs. I used the constant comparative method on this sample, reviewing the data many times, and extracting a collection of interrelated concepts. I built a descriptive framework from these concepts, centered around a core concept. I then applied the framework to further data, and continued to refine the descriptions and definitions of the various concepts through agreement exercises with another researcher. In following this process, my methods used both inductive and deductive analysis, differing somewhat from grounded theory, which continues using inductive analysis to refine concepts until they are firm.

This analysis differs in two other ways from the defined course of grounded theory methodology as well. First, the primary data gathered for grounded theory analysis is most often interview data (Creswell, 2007). As mentioned above in Section 3.1.1, I chose not to use interviews in this study. This means that my analysis is based on observations, limiting what I can infer from the data. Any explanations accompanying my descriptions in this framework are only speculative, as I have not acquired participants' accounts of the events, nor am I attempting to understand the events from their perspective beyond what is shown in the observational data.

Second, Corbin and Strauss recommend beginning analysis as soon as the first pieces of data are collected and collecting further data guided by the analysis. However, my strategy toward analysis changed over time and initially included a blend of grounded theory with other frameworks. Thus, I came to use grounded theory more fully after the collection of my data. Rather than relying on the collection of further data through the analysis, I sampled the

data from the existing pool of data in accordance with Corbin's and Strauss' recommendations (Corbin & Strauss, 2008, p. 150).

Chapter 4

Analysis: The Issues Framework

In Chapter 3, I introduced grounded theory as my method of analysis and gave an overview of how I used the method to build a framework from my data. As I mentioned in Section 3.6.1, grounded theory involves the emergence of concepts - micro and macro themes - that apply to the data. In my analysis, a major concept emerged around which I develop the framework. This is the concept of Issues. The concept of Issues initially emerged from reviewing the GTA-student interactions in my data. I noticed that almost all GTA-student interactions focused on a procedural move in the problem or a conceptual idea that the students were either uncertain about or had incorrect. Looking before the interaction then, I could identify places where students' created these errors and uncertainties in their process that came up in GTA-student interactions, and I could follow them through to their conclusions. With this perspective, I could describe how the GTA-student interactions were situated in students' processes. Anchoring the framework in the concept of Issues, then, would provide a basis for answering my research questions. Below I define what Issues are in more detail, and I develop the framework that emerged around this central theme.

In this chapter, I walk through the creation of the Issues Framework following first a simple, then a more complex example from my data. I then discuss the coding tasks designed to apply the framework to further data. Finally I review the agreement tasks I and another researcher

completed to check reliability and validity of the framework.

4.1 Development of the Issues Framework

In this section, I will develop the Issues Framework. The framework is made up of many features emerging from the data. These features bring to light the physics content students express and moves students make as they work through a physics problem as well as identify how the GTA interacts with the students during this time. The framework and its features allow me to answer the research questions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

To assist in developing the framework, I will build a visual diagram as I proceed, adding each new feature to it. The design of the framework diagram is intended for easy visual pattern matching of a complex system of features. I do this through purposeful spatial structure, layering, and color. This makes the framework a useful tool for condensing complex data into a manageable story and visually identifying patterns in that story. Figure 4.1 shows an outline of the complete framework diagram structure with no features present. I place it here as a precursor to the development of the framework to provide a sense of the final structure. I describe both the structure and individual features as I develop the framework. Initial mentions of key words that make up the framework will be bolded **red** for clarity. Additionally, I will continue to clarify and solidify these features and the final framework in an example. Once complete, I will review building the structure of one additional, more complex example. However, I will not be able to cover examples of every single feature. A full set of feature characteristics and examples can be found in Appendix B.

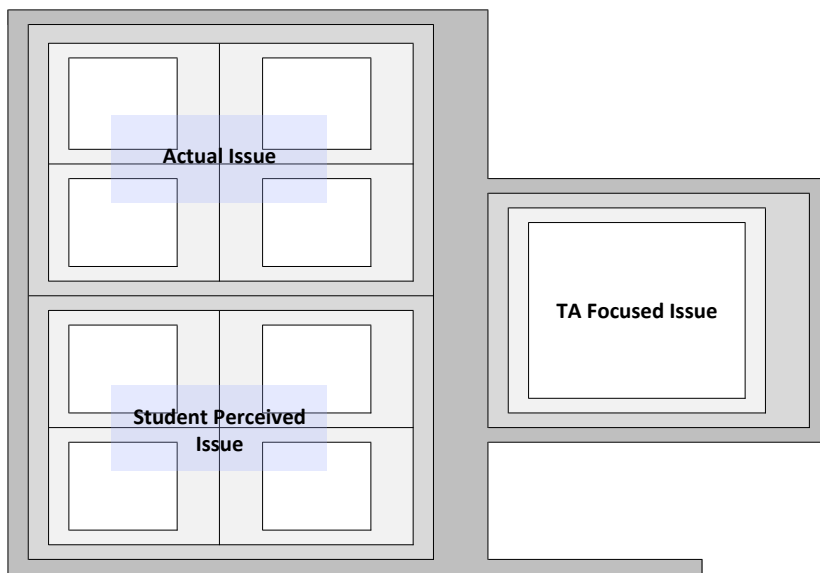


Figure 4.1: An outline of the framework diagram shows the location of the three kinds of Issues identified in the framework as well as the basic structure of the framework diagram. The four innermost white squares at the top left make up the Actual Issue. Those at the bottom left make up the Student Perceived Issue. The inner white square on the right is the GTA Focused Issue. Features will wrap around these squares in the different gray layers. Time will be indicated by the location of the features along the top of layers (before the interaction), the side of the layers (during the interaction) and the bottom of the layers and the bottom extended arm (after the interaction).

While the framework is fully emergent from the data, multiple previous studies influenced my analysis. I discuss these influences in Section 4.1.7 below the development of the framework. I discuss it *after* I develop the framework so the readers’ understanding of the influences can be grounded in the framework.

Before beginning to develop the framework used to answer my research questions, I clarify what is intended by “procedural moves students make” and how it is distinct from “physics content students express.” A procedural move is a *specific decision and the resulting action or inaction decided upon* that students make when working through an activity. This is the decision and subsequent action made about “what to do next.” Procedural moves may contain physics content and may be motivated by discussions of physics content. But the procedural

moves themselves are solely the decisions and actions made during an activity.

The example introduced in Chapter 1 further illuminates this distinction. In that example, S3 states repeatedly that work is zero. Identifying that the work is zero is an expression of physics content that fits best under the first research question. After repeating that work is zero and allowing S1 to express his physics content ideas, S3 decides to set work to zero, completing the equation in the students' solution by writing a "0" in for work. The decision to use $W = 0$ and the writing in of that part of the expression in the students' solution is a procedural move, fitting under the second research question. The procedural move inherently contains the physics content idea that work is zero, but is in itself the decision and act of taking that step explicitly in the problem. I further detail this distinction through the development of particular features of the framework below.

4.1.1 What are Issues

As students work through a physics problem, there are one or more appropriate problem solving paths they can take. I define an appropriate path as one in which every step moves students closer to the correct answer. **Issues** are the deviations from and obstacles along an appropriate problem solving path. Issues are revealed through the **Errors** students make and **Uncertainties** they express as they follow a problem solving path. I define Errors as inappropriate procedural moves or ideas. And I define Uncertainties as students' displays of lack of confidence towards a particular procedural move or idea. Students' Errors and Uncertainties form the basis of Issues.

Certain Issues are addressed and resolved by the students amongst themselves. Others lead to interactions between the students and their GTA. The Issues Framework only examines Issues that are brought up, in any way, during those GTA-student interactions.

Additionally, when GTA-student interactions occur while students are working through a physics problem, Issues are almost always the foci of the interactions (i.e. not all Issues

lead to interactions, but almost all interactions focus on Issues).¹ Thus, Issues are the central relationship between the GTA-student interactions and the physics content students express and procedural moves they make in and surrounding the interactions.

Each Issue students create is constructed of one or more Errors or Uncertainties centered around the topic of the data segment. Additionally, Issues may contain supporting information shared by the students. Given this, all Issues have four possible components. Each Issue may be distributed among one or more of the components.

- **Conceptual (C)** - a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement
- **Conceptual Why (CWhy)** - reasoning behind the conceptual idea
- **Procedural (P)** - a move to be made during the construction of a solution or concerning the following of specific instructions
- **Procedural Why (PWhy)** - reasoning behind the procedural move
 - Procedural Why and Conceptual can be the same thing, as often (but not always) the motivation for a move is a conceptual idea.²

The particular details of these four components make up the physics content students express and the procedural moves they make.³ All four components can contain physics content, but the moves students make is contained in the P component only. These components contain the details, or contents, of each Issue. The Issue is then made up of one or more Errors or Uncertainties in one or more of these components as well as additional supporting information also distributed into the appropriate components.

¹Occasionally, GTA-student interactions will focus on administrative topics (e.g. sign in sheets, acquiring extra whiteboard markers, etc.). These are not included in this study.

²When they are the same, arrows will appear on the diagram indicating this.

³I refer to the details of the components as the contents of an Issue. This contains physics content and procedural moves. Where I intend physics content, I will use the term “physics content.” Where I intend Issue contents, I will use the more general “contents.”

These four components that construct the Issue are the anchor of the framework. All that I develop after this is tied to this anchor. This, then becomes the first piece of the diagram. In Figure 4.2, the specific components of each Issue are displayed among the boxes appropriately. In particular examples (as I get to next), any Issue contents are written into their appropriate components. Any box that is unused remains essentially blank (labeled only).

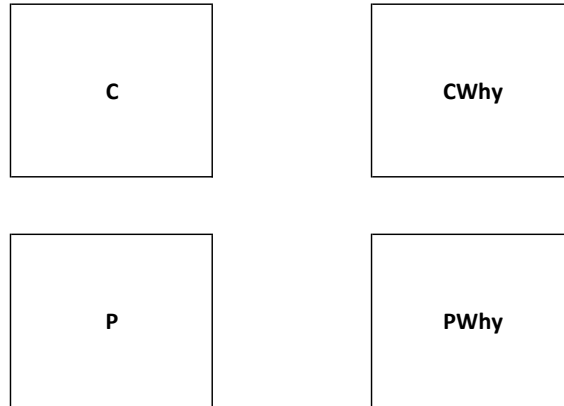


Figure 4.2: The innermost layer of the diagram, the four components of the Issue, are shown. They are labeled accordingly: C - Conceptual, CWhy - Conceptual Why, P - Procedural, and PWhy - Procedural Why.

Example: Determining the Issue

I will re-introduce our primary example from Chapter 1 to help clarify this. I will follow this particular example as I put together all the features of the framework. As a reminder, in this example, students have been asked to calculate the initial speed of a ball tossed directly up once it leaves the hand. The complete problem statement can be found in Appendix A. Students are instructed to use the energy principle for the system of just the ball (see Section 3.2.2). In the example, they have written the energy principle for their solution: $\Delta K = W$. In Section 3.5.1, I described creating data segments around the specific topics seen during GTA-student interactions. As exemplified in that section as well, the topic of the data segment I use for this example is the work term of the Energy Principle. First, I will examine the dialogue to see what

Errors and Uncertainties arise surrounding the topic of work.⁴

1 **S1:** Change in kinetic energy equals work. Ah, work is zero, because you're- it's the sur-
2 roundings... well...

3 **S2:** Well, then, how do you calculate the velocity if work is zero?

4 **S1:** 'cause your kinetic energy final equals fin-K, no, it needs...

5 **S2:** So...

6 **S1:** In this scenario, um, kinetic energy's going to be one half m v squared.

7 **S2:** And work,

8 **S1:** So it's going to be your final velocity minus your initial velocity.

9 **S3:** So final velocity equals initial velocity.

10 **S1:** Then your work- Your work is either going to be your gravity calculation then, or it's
11 going to be zero.

12 **S3:** It should be zero.

13 **S1:** Cause if you're choosing your surroundings to be, um, just the ball, you have to take
14 into effect gravity.

15 **S1:** But if you choose to make gravity, um, you include it in your system, then it's zero,
16 because there are no other forces acting on it.

17 **S2:** But it can't have zero in it, because zero makes everything zero.

18 **S1:** But, it doesn't necessarily, because if you chose to have the ball and gravity in your
19 calculation, your'e going to have more kinetic energy you have to calculate, so...

20 **S3:** (Writes out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard)

21 **S1:** one half m v squared final...zero.

22 —————- (**Interaction Begins**)

23 **GTA:** Why is the work done zero?

24 **S2:** hmm?

25 **GTA:** Why is the work done zero?

⁴For easier reading, this and all following transcription in this chapter will be written as seen here, rather than in the three-column, one-second segmented format.

26 **S2:** It's not?

27 **S1:** No. It's not zero.

28 **S3:** It won't be zero?

29 ————— - **(Interaction Ends)**

30 **S2:** Work equals... I can't remember the formula for work.

31 **S1:** No, work - Yeah, work is just, um, F_x times Δx plus F_y Δy plus, F_z Δz
32 z , all added together ($F_x * \Delta x + F_y * \Delta y + F_z * \Delta z = W$).

I will first examine the dialogue before the interaction, as that is where the Issue develops. What happens here is the generator of the Issue. Then I'll review the dialogue during and after the interaction for any information that might further clarify the Issue. Clarifications might cause me to adjust wording of the Issue a bit but will not add on components not already present.

I notice one immediate Error as S1 begins with "Work is zero" in line 1. The instructions state, "For the system of the ball, write the Energy Principle for this specific situation..." This ensures students will treat the earth as an object in the surroundings, requiring them to use a non-zero work term in their solution. Thus, work can not be zero since the required system, per these instructions, contains only the ball. This idea that work is zero is, as stated above, an Error. S1 seems to falter at the end of the first line which may or may not be faltering specifically about the value of work, but there is some Uncertainty there. S2 comes back to challenge the idea in line 3, and S1 continues trying to explain himself, faltering in line 4. So far, the defense is focused on justifying $W = 0$. S1 continues describing the circumstance in which work would be zero and that in which it is not in lines 10 - 18. S3 decides that work should be zero in line 13, and in line 20 continues the groups' solution construction on that settlement.

While there is a lot of reasoning given in this example, whether or not work is zero and then deciding that it is zero seems to be the students' primary focus. The decision on the value for

a particular term is a procedural move (that contains physics content in this example).⁵ Thus, this Issue will contain at least a procedural component.

I briefly check the dialogue during and after the interaction to see if there is anything more clarifying before putting this into the diagram. I see a focus specifically on work being zero during the interaction (lines 23 - 28). And I see students are changing work after the interaction (lines 30 and 31). Thus, no real new information on the Issue is revealed, and the Procedural component stands as is. Figure 4.3 shows this in the diagram.

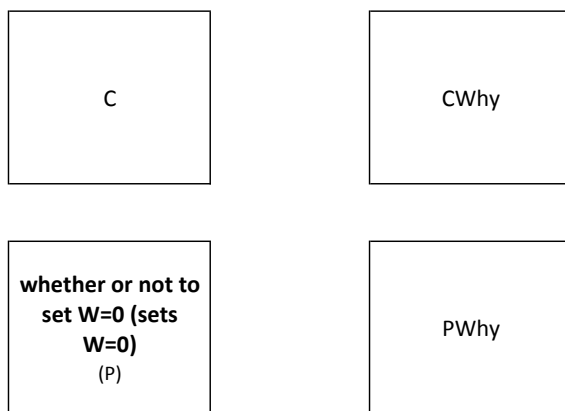


Figure 4.3: The inner layer of the example Issue has the P component filled in with its respective contents. Other components not yet filled in remain labeled accordingly.

Now I re-examine the dialogue to better understand the full argument and identify any other components. In line 1, S1 begins justifying work being zero “because you’re - it’s the surroundings.” This is a partially correct statement of reasoning, if a bit unclear. Work does deal with the surroundings. It seems, in lines 6 and 8, S1 is re-mapping the energy principle, beginning with kinetic energy. However, there is no real reasoning here. He then backtracks to

⁵Reasoning supporting that decision would be distributed into the other Issue components as appropriate. If an Issue displayed very clear statements of reasoning and procedure together (e.g. “There are no objects in the surroundings, so work is zero”), both reason and decision would be considered central to the Issue and distributed to the appropriate Issue components. “There are no objects in the surroundings,” would become the contents of the PWhy component, and “Work is zero,” would be the contents of the P component.

specifically talk through the reasoning for setting or not setting work to zero in lines 13 - 18 (with another challenge from S2 in line 17). S1's argument progresses thus:

1. This (work being zero or not) depends on whether your system includes or doesn't include gravity. (lines 13 - 15, PWhy/C - a conceptual idea about work (C) that also explains the reasoning behind the procedural move (PWhy))
2. No other outside forces acting if gravity is included in the system. (line 15, CWhy - reasoning behind what the the inclusion and exclusion of gravity means)
3. There will be more kinetic energy to calculate if the ball and gravity are both in the system. (line 18, CWhy - reasoning behind what the the inclusion and exclusion of gravity means)

Looking at these lines, I see that S1 provides reasons why work might or might not be set to zero using a conceptual idea about physical systems. He then supports the reasoning behind this concept with both the idea that there would be no external forces if gravity were included AND kinetic energy would increase to account for gravity being included. This adds on a PWhy/C and a CWhy component to this Issue. Again, checking the dialogue during and after the interaction shows a focus specifically on work being zero during and then changing afterward (lines 23 - 31). Again, no real new information on the Issue is revealed, and it stands as is. These components are mapped out in the Issue box accordingly in Figure 4.4.

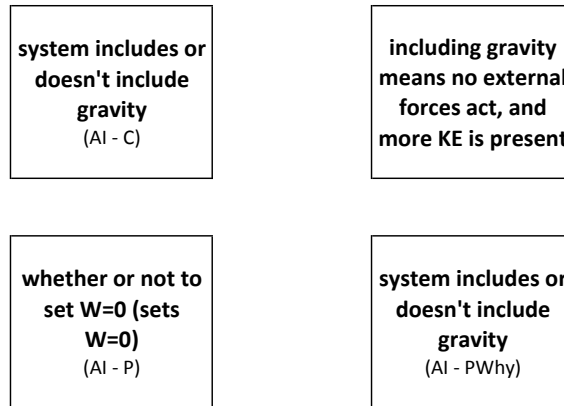


Figure 4.4: The inner layer of the example Issue is completely filled in with the contents of each component. The components locations remain the same with C (upper left), CWhy (upper right), P (lower left), and PWhy (lower right)

Issue Creator

I now have the entire Issue mapped out and am ready to move forward with the framework. Before I do, however, I will take a moment to solidify the identification of the Issue creator. The Issue creator is the student or students who are primarily responsible for the creation of the Issue. The Issue creator is determined by a few factors:

1. who specifically makes an Error in the procedural move and/or idea
2. if there is no Error, who expresses Uncertainty about an idea or procedural move (If both Error and Uncertainty are present from different students, the student who made the Error is typically the Issue creator. This is adjusted to multiple students if active debate is occurring.).
3. the majority participation of a particular student in creating the Issue (Multiple group members can contribute to an Issue, but if one student stands out as contributing the most in terms of Errors and Issue components, that student is the Issue creator. If multiple students equally contribute independent ideas and/or procedural moves to the creation of the Issue, all students involved are Issue creators.)

Many of the framework features developed in the following sections apply only to the Issue creator. This allows me to focus on the process of the student(s) who made the Error and/or expressed Uncertainty about an idea or move. Issue creators usually do not work alone, however, and other features below will pertain specifically to either the remaining non-Issue creating students, *any* individual student in the group, or the group as a whole. These assignments are specified as each feature is introduced.

Returning to the example, I identify the Issue creator. S1 clearly has laid out most of the argument for this Issue. He initially called work zero, and he was the group member who was challenged by S2 for his idea. Thus, he is the Issue creator for this Issue. Of course, he did not work alone, and so I'll briefly review the other group members' roles. S2 was opposed to some idea in the Issue. Thus, S2 could not have created the Issue. The idea did not come from him. S3 was the instigator of actually setting work equal to zero. So he did assist in creating the Issue. His participation in the group, however, is minimal compared to S1. He is ignored initially and only has attention paid to him by S1 as he begins to write out the energy equation with work set to zero. Thus, he does not assert himself in the group, nor develop enough of the ideas of the Issue to truly be a creator. Both S2's and S3's roles will be accounted for later when I discuss the nature of the creation of the Issue.

Thus far, the process of determining Issue contents comes before determining the Issue creator. However, one could reverse this process, selecting each student in turn (or the whole group) and then identifying the details of the Issue that pertain to each student. This will initially provide different perspectives on the Issue. From that point, one could select one or more student perspectives to analyze further. Or one could merge perspectives together to arrive at the same or very similar state as the original process (determining Issue contents first) shows. Initially, I found this process a useful exercise to better understand the varying perspectives and roles students take in creating the Issue. Ultimately, however, this reversed process was far more time consuming than the original process to reach a very similar state. Thus, I decided to continue analysis using the original process. I describe the reverse process

to show its plausibility and to show its value in understanding perspectives on the Issue.

Having solidified the Issue creator as S1, I will color his “name” red in all future uses of the transcript. Additionally, I will color the names (S1, S2, and/or S3) red of all Issue creators in the transcripts of future examples in the rest of this chapter and in Chapter 5.

Student Perceived Issue Contents

What emerged next in the data was that, for some Issues, students were aware an Issue existed. For other Issues, they were not aware. In some segments, they would create an Issue seeming unknowingly and not realize it until it was brought up in an interaction. In others, the Issue was central to the dialogue. And in a small number of segments, the Issue seemed to cause a secondary Issue: the secondary being the Issue that made students aware something was amiss. Due to these varied situations I observed, I pulled out two kinds of Issues: the **Actual Issue** and the **SPerceived Issue**.

Actual Issue (AI)

- The Actual Issue is the root Error or Uncertainty that requires Resolving as seen by the researcher/physics expert.
- The creator of the Actual Issue is often a single student but can be multiple students.

The Issue I pull out above in the example is an Actual Issue. From here on, I refer to it as the Actual Issue (or AI) rather than just “the Issue.”

SPerceived Issue (SPI)

- The SPerceived Issue is the Issue students think they have. These are Uncertainties (not Errors) unless students perceive that they have made an Error specifically. The SPerceived Issue can be one of two things:
 - Same - Students perceive the same Issue as the Actual Issue.

– Different - Students perceive an Issue that is not the same as the Actual Issue. Sometimes, the perceived Issue follows from an Actual Issue.

- The SPerceived Issue may be created by the Actual Issue creator or other students.⁶

In some cases, students do not perceive an Issue.

The contents of the SPI are decided on in a similar manner to that of the AI. The SPI then easily fits into the same components as the AI. A difference between them is that the SPI can have zero contents if students do not notice there is an Issue. I add Issue boxes to the initial diagram that will house the SPI. The next step of the diagram can be seen in Figure 4.5.

⁶The focus of the Issue creation in general, however, is on the Actual Issue creator. Thus, If the Actual Issue creator acknowledges the creation of the SPerceived Issue by another student, he/she is incorporating that SPerceived Issue into his/her process. So all SPerceived Issue framework features will be assigned to the Actual Issue creator. If there is no acknowledgement by the Actual Issue creator, then the SPerceived Issue will be assigned to the other student who created it. However, I only saw this once.

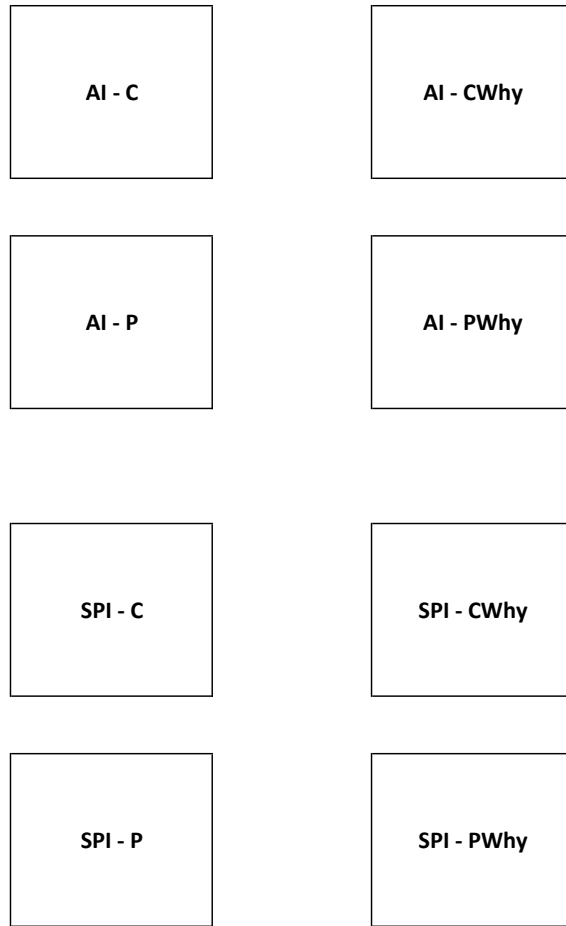


Figure 4.5: The inner layer now divided between the AI and the SPI, each with their four components labeled.

As a final note before reviewing the example, I officially leave students' concerns about their final answer out of the SPI altogether unless the students have checked their answer in WebAssign and it has marked them wrong. I do this under the general notion that students are never fully confident about their answer until checking it with some authority figure, WebAssign, or the GTA. As a default, there is always an Issue with the final answer. Due to the difficulty of separating out students' cognizance of the possible correctness of the final answer in the different data segments, I chose to ignore it altogether unless WebAssign made it certain

to the students that they had an Issue. I discuss the ramifications of this decision toward the end of the results in Chapter 5.

Example: Student Perceived Issue Contents

I'll examine the transcript of the example to see how the SPI is revealed. S1 shows initial hesitation in line 1 that seems to suggest he is rethinking his statement about work being zero. S2's challenge in line 3 shows S1 that at least one other student sees an Issue with his idea. This does not go away for S2, but only gets restated later on in line 17 as S2 rebuts the idea of setting work equal to zero. S1 again shows his hesitation in setting W to zero in line 10 when he states the two possible situations. This indecision followed by S3's decision to set work to zero makes it clear that the students are aware they have the Issue of whether or not they are setting work equal to zero. Thus, the SPI will contain this procedural component.

Examining lines 13 - 18, I see S1 talk through his reasons with no hesitation or any evidence that indicates he might see something wrong with his own reasoning. Even S2's challenge in line 17 (which is directed only at the procedural component, not the reasoning) is met with a confident defense from S1 in line 18. There is nothing here that gives evidence to an SPI in the remaining components. Acknowledging this, I can put together more of the diagram for this example. Figure 4.6 shows this.

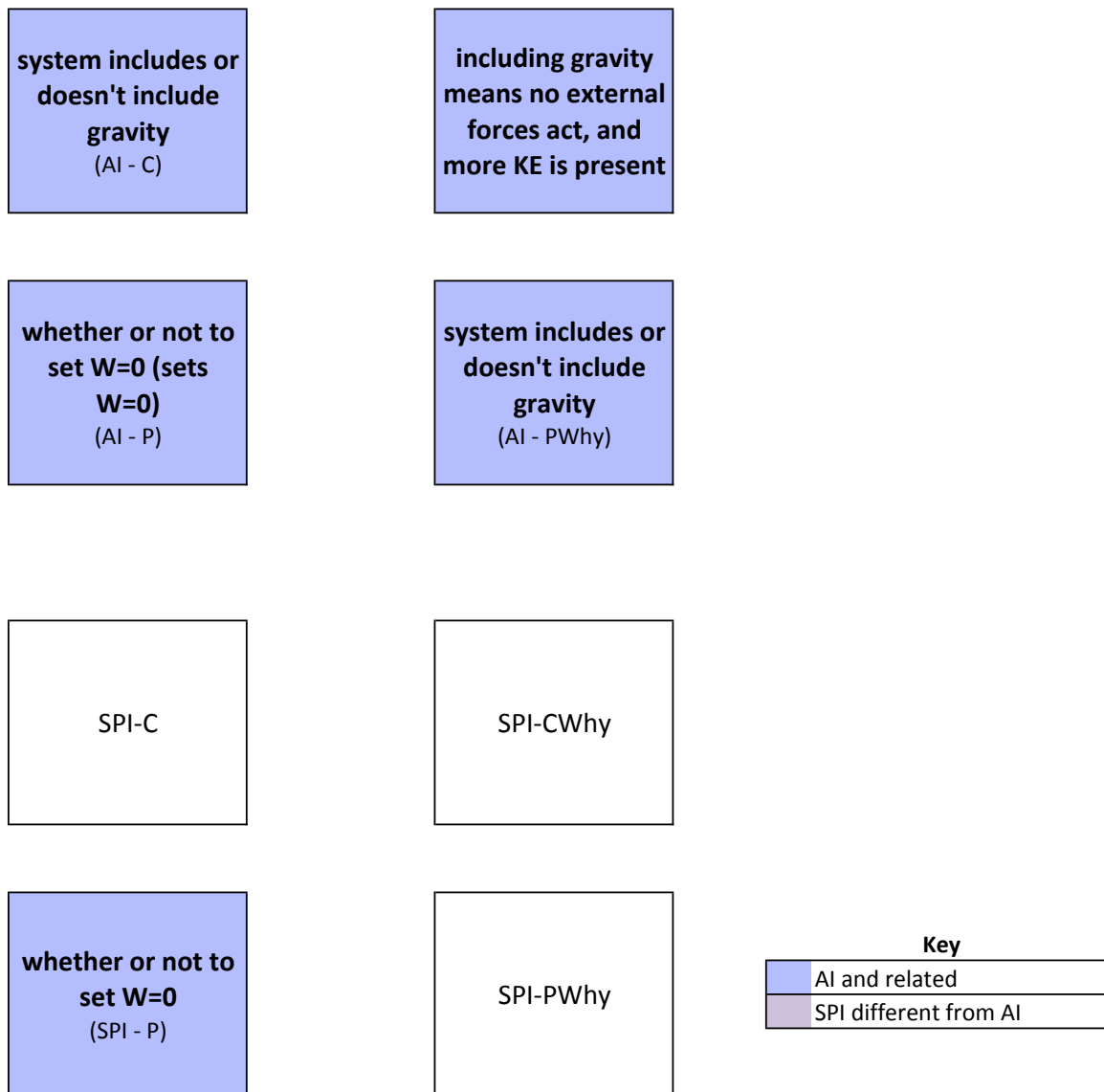


Figure 4.6: The inner layer of the framework for the first example Issue has all components of the AI and SPI filled in. Blank components remain uncolored and labeled only. The AI is always blue. The SPI is blue in this example, as it is the same as the AI. The key differentiates between the AI (blue) and the SPI (purple), should the SPI ever differ from the AI.

There is a difference in wording between the AI - P and the SPI - P, though they are not different Issues. The students see an Issue with the procedural component, granting its presence

in the SPI. However, S3, in setting work equal to zero, makes the appearance of this Issue go away temporarily so the students can move on. Thus, the fact that work is actually set to zero eventually adds a slight further complication to the AI - P, but not to the SPI - P, as it is the statement that temporarily makes the SPI go away.

I have now added some color to the diagram along with a key. All components of the AI and SPI are blue. I will now always color the AI blue in examples. A blue SPI indicates that the SPI component(s) present is the same as its AI counterpart. When they are different, I will color the SPI purple. Note here that the nature of the SPI - whether or not it is the same as the AI or different - has not been validated. I include it here for completeness.

No Issue

In some cases, students do not create an Issue before an interaction. However the GTA introduces a topic during the interaction that could be a possible current or future Issue. This topic is discussed during the interaction and thus influences the students' moves after the interaction. It also connects to the students' process before the interaction by bringing out physics content and procedural moves that were not Issues initially. For these reasons, I include these "non-Issues" in the dataset. I'll return to them when I identify Issue content categories.

Error and Uncertainty

Now that I have completed identifying the contents of the AI and SPI, I will return for a moment to the concepts of Error and Uncertainty that underly the identification of Issues. I want to be able to identify specifically for which AI components Error and Uncertainty are present. I do not necessarily expect them to be present in every component, and using them to identify the Issue does not always give the specific detail needed for all components in all cases. Additionally, I'd like to validate their presence in the specific components as that lends strength to the identification and final discussions. Finally, identifying the Error and Uncertainty in each component gives more information about the physics content expressed and procedural moves

made. These features pertain to the Issue creator, as the Issue creator is the one making the Errors and expressing the Uncertainties that become the Issue.

The presence of Error indicates the correctness, or lack thereof, of the physics content or move. Uncertainty indicates whether there is a lack of confidence by students in their idea on the physics content or move. Thus, Error and Uncertainty also become features of the framework, with the possibility of being present in any of the components containing Issue contents.

Additionally, I add them as features to the SPI with a slight difference in the definition of Error. Error in the SPI relies on students specifically thinking they are wrong about some (or all) component of the Issue. This is more difficult to tease out and needs to have stricter boundaries. Students may think something might be wrong but don't know what that is. Or it might seem that students must know they're wrong, but they are not necessarily explicit in identifying that. Thus, Error only exists in this framework if students explicitly state that they must be wrong about a component of (or all of) their SPI. Uncertainty remains defined in the same way as in the AI (based in students' questions, hesitations, and statements). Figure 4.7 shows Error (E) and Uncertainty (U) built into the diagram.

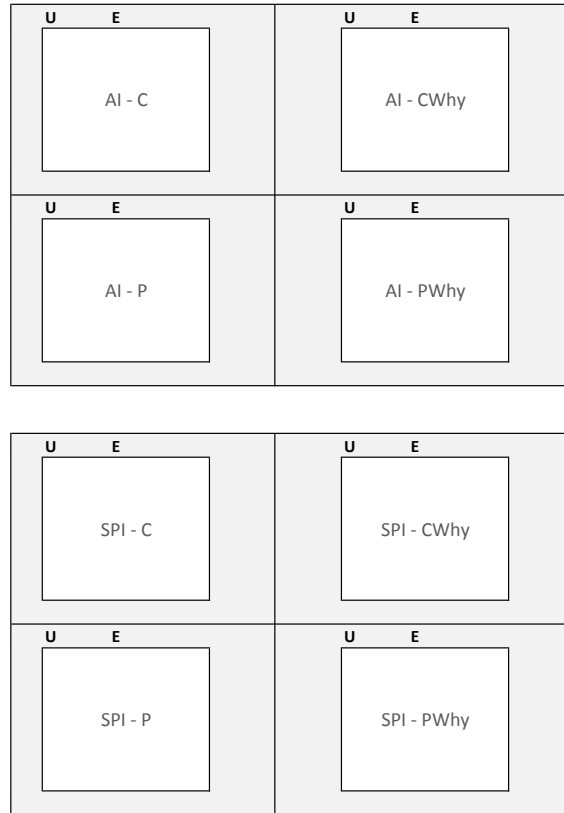


Figure 4.7: A second layer is added around each component of the inner layer of the example Issue diagram. This layer displays Uncertainty (U) and Error (E) for each component of the AI and SPI.

At this point I have added on another layer to the diagram. Each Issue component for both the AI and SPI has been wrapped by an outer box. These boxes will contain all the features that are relevant to each individual component respectively. So far, these are Error and Uncertainty. I will continue to add more as I progress through the Issue development. But first I'll revisit the example and specifically identify the Errors and Uncertainties.

Example: Error and Uncertainty

I use the contents of the Issue boxes in Figure 4.6 to guide toward the specific dialogue to focus on. Then I examine that dialogue for Errors and Uncertainties. Starting with the AI - P

component, I see S1 make an Erroneous declaration in line 1. However, he then falters at the end of line 1. Further along in line 10, S1 talks about whether or not work is zero, not really making a specific decision. Finally, S3 chooses to set work to zero, and S1 goes along with it. In solidifying the decision to make work zero, there is officially an Error in this component. Seeing as this Error was made with initial hesitation and indecision, there is also Uncertainty in this component.

I apply similar reasoning to the SPI - P component. S1 is Uncertain about whether work is zero. S3 solves this by setting work to zero. The SPI - P component does contain this Uncertainty. In order to contain Error, the Issue creator must identify that he thinks he is wrong. S1 one does not do this, and so the SPI - P does not contain the Error feature. In this example, S2 *does* identify an Error in S1's reasoning. I will extrapolate on S2's role and account for his declarations in the next section. His role does not get included in marking the SPI - P with Error for two reasons:

1. he is not the Issue creator (Error and Uncertainty pertain to the Issue creator.)
2. he specifically asks questions and makes declarations about how something seems impossible. He does not, at any point declare it as outright wrong.

I'll move on to the PWhy and C components of the AI. They are the same, so I only need to analyze once. The argument given by S1 is that setting work to zero depends on whether gravity is included in the system (lines 13 - 15). While he misconstrues his words slightly, his reasoning is correct. Setting work to zero is dependent on what is included in the system and surroundings. He also shows no signs of hesitation or other Uncertainty in saying this. Thus I do not mark this component with either Uncertainty or Error.

Finally, I look to the CWhy component. S1's argument concerning what happens in one situation versus another is mapped out in lines 15 and 18. He does not show any hesitation, questions or other signs of Uncertainty here. His first line of reasoning, that including gravity in the system means there are no other forces acting is, in fact, correct. However, his second line

of reasoning, that there will be more kinetic energy if gravity is included in the system, is not correct. Thus, the CWhy component is marked with Error. Figure 4.8 shows this analysis in the diagram.⁷ Note that there are now arrows pointing between AI - C and AI - PWhy, indicating that they share the same contents. These arrows will show up in this layer anytime those two components match in any of the AI, SPI, and TAFI.⁸

⁷There are no features added around the remaining SPI components. Since these components don't exist for this Issue, I keep the diagram simpler and clearer by not adding in all the features.

⁸TAFI will be introduced and developed later.

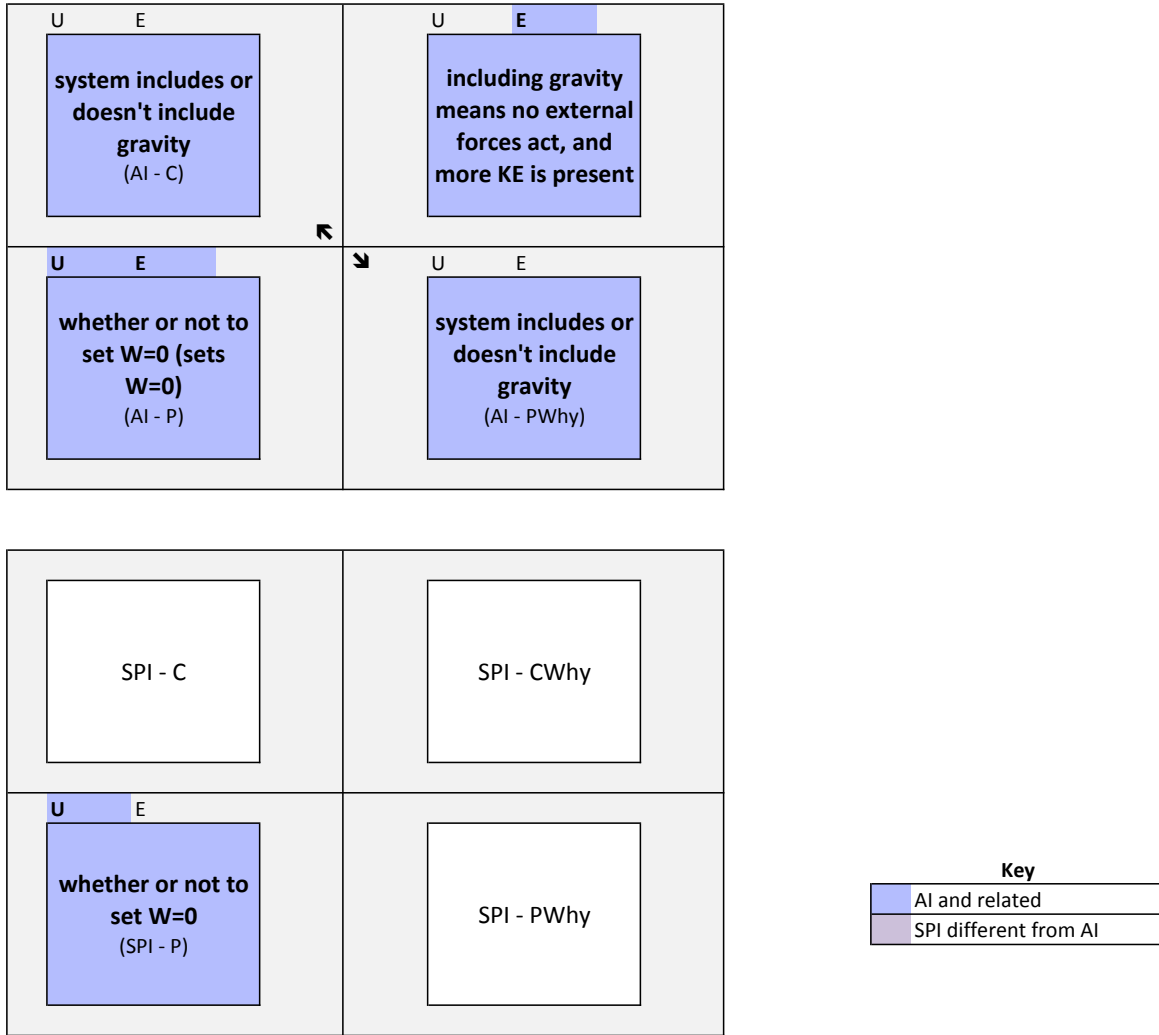


Figure 4.8: A second layer is added around each component of the inner layer of the example Issue diagram. This layer displays Uncertainty (U) and Error (E) for each component of the AI and SPI. U and/or E are highlighted above components in which they are present - AI - P, AI - CWhy, and SPI - P - in the example Issue. Additionally, the presence of the diagonal arrow in the center of the AI indicates that the C and PWhy components share the same contents

This finalizes the full mapping of what Issues are and whether they contain Errors and Uncertainties. I'll now shift focus to how the Issue is created.

4.1.2 Pre-Interaction: How Issues Are Created

The features that emerge in this section reveal more about how the Issue creator(s) comes up with the physics content and moves of the Issue. They also reveal whether other students in the group agree with the Issue creator, or whether they are uncertain or against a move or idea.⁹

In discussing the creation of the Actual Issue, I talk about it as a whole. I do not discuss the creation of individual components (C, CWhy, P, PWhy). I do this primarily to avoid fragmenting the creation too much as that would cause confusion about how the Issue arises. I prefer to understand how students create the Issue as a whole. Later, when I talk about Resolutions, I'll move back to identifying them in individual components. I only focus on the AI in this section. A brief look at the SPI possibilities reveals why:

1. SPI nonexistent - There is no creation to be concerned with.
2. SPI same as AI - The creation will then also be the same.
3. SPI different from AI - The creation of the SPI still comes as a result of the creation of the AI and does not warrant its own attention.

Nature of Issue Creation

The whole of the AI is created in one of two ways:

- **Automatically (Au)** - seemingly from thin air, without observable evidence of purposeful thoughtfulness. These are often procedural moves made without any discussion surrounding them (e.g. scribbling out a formula or principle from memory without discussing if and why certain terms should be included or excluded). This pertains to the Issue creator.
- **Thoughtfully** - through discussion of ideas or quiet contemplation. This typically involves a statement or question of a concept and/or procedure followed by challenges to

⁹This section is less important if all three students are Issue creators.

the ideas or moves; questions about them; or reasoning and support for them.¹⁰

Within these two categories, several discussion features may influence the creation.

- **Independent (I)** (Thoughtfully only) - The Issue creator develops the Issue independently (through statements, questions, or obvious quiet contemplation), but might read through something or talk aloud some reasoning to do so. There is no input from other students. The quiet contemplation is determined in part by the length of time the creation takes, as well as by body language.
- **Question Generation ($Q_{a,na}$)** (Thoughtfully only) - The Issue creator generates the Issue by asking a question. It does not matter whether or not anyone answers (though I will mark the presence of an answer in the framework), simply whether the initial generation was in the form of a question.
- **Challenge (Ch)** - The Issue creator develops the Issue either Automatically or with some reasoning and one or more *other* students challenge the Issue's correctness of sensibility.
- **Question (Qi)** - The Issue creator develops the Issue either Automatically or with some reasoning and one or more *other* students ask a question(s) concerning the Issue
- **Collaborate (Co)** - Students build an idea together. This Issue creator and at least one other student contribute unique information to the Issue. There may be multiple Issue creators as well.

Figure 4.9 shows the diagram with these features added in. I have now built another layer into the diagram as well. The frame in which the creation features sit wraps around all components of the AI together. For completeness, I put the same frame around the entire SPI, but I will not use it in this framework.

¹⁰This feature does not show up on its own in the diagram, but is present through the presence of its characteristic features, Independent, Question Generation, and Collaboration.

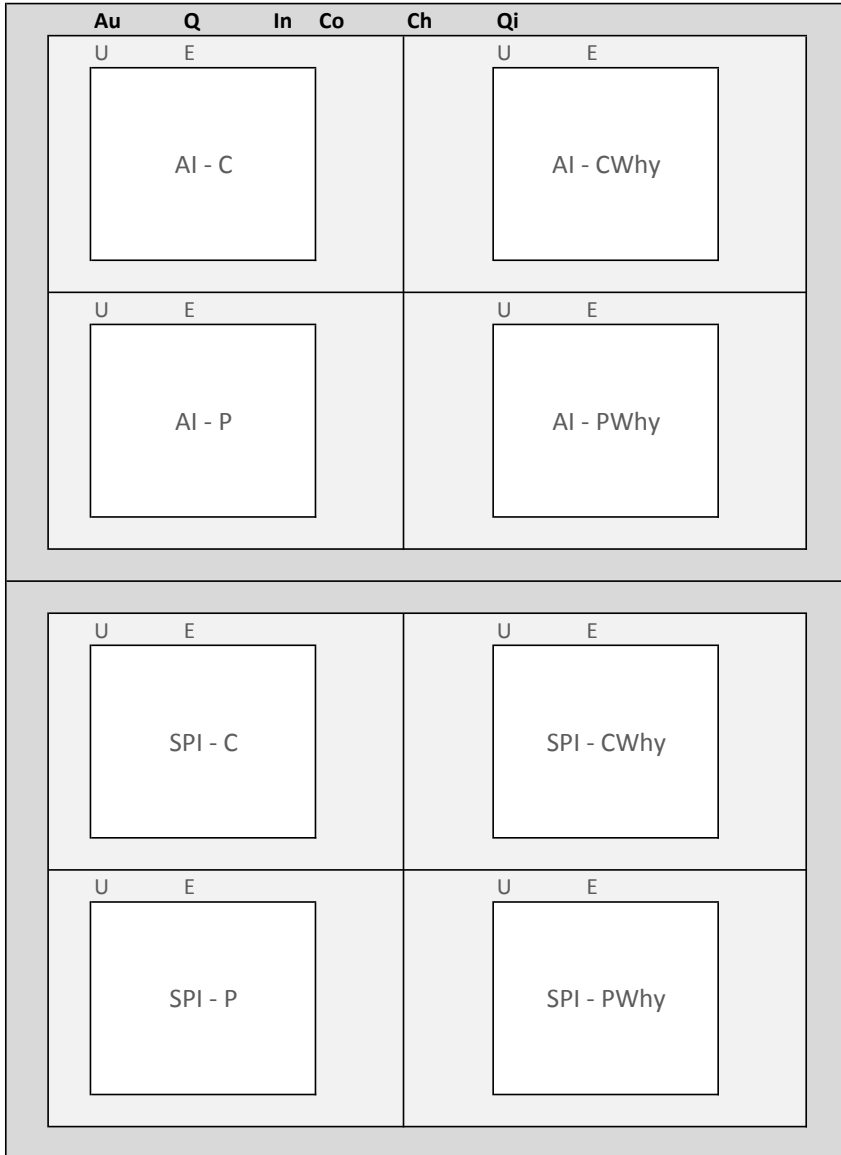


Figure 4.9: A third layer is added around the second layer. This layer enwraps all components within each, the AI and SPI. This layer displays the creation features - Automatically (Au), Independent (I), Question Generation ($Q_{a,na}$), Challenge (Ch), Question (Qi), Collaborate (Co) - for the AI.

Example: Nature of Issue Creation

I review the example to determine the features represented in its creation. I repost the dialogue below for ease of analysis. As mentioned above, S1 will now be highlighted in red to identify him as the Issue creator.

33 **S1:** Ah, work is zero, because you're- it's the surroundings... well...

34 **S2:** Well, then, how do you calculate the velocity if work is zero?

35 **S1:** 'cause your kinetic energy final equals fin-K, no, it needs...

36 **S2:** So...

37 **S1:** In this scenario, um, kinetic energy's going to be one half m v squared.

38 **S2:** And work,

39 **S1:** So it's going to be your final velocity minus your initial velocity.

40 **S3:** So final velocity equals initial velocity.

41 **S1:** Then your work- Your work is either going to be your gravity calculation then, or it's
42 going to be zero.

43 **S3:** It should be zero.

44 **S1:** Cause if you're choosing your surroundings to be, um, just the ball, you have to take
45 into effect gravity.

46 **S1:** But if you choose to make gravity, um, you include it in your system, then it's zero,
47 because there are no other forces acting on it.

48 **S2:** But it can't have zero in it, because zero makes everything zero.

49 **S1:** But, it doesn't necessarily, because if you chose to have the ball and gravity in your
50 calculation, your'e going to have more kinetic energy you have to calculate, so...

51 **S3:** (Writes out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard)

52 **S1:** one half m v squared final...zero.

I examine the presence or absence of these features in the example.

- Automatically (Au) - S1's first statement in line 33 is Automatic, as he initially doesn't think twice about the value of work. However, by the end of line 33 he is already begin-

ning to rethink his statement. A very Thoughtful reasoning follows, so this Issue is not developed Automatically.

- Thoughtfully - I have just determined by eliminating Automatically that the Issue is created Thoughtfully.
- Independent (I) - S1 receives feedback from both S2 and S3, so this Issue is not created Independently, even though the main line of reasoning belongs to S1. This can be eliminated.
- Question Generation (Q) - S1 initiates the Issue with a statement in saying "work is zero". There is no question present, even as he begins to rethink his idea. This can be eliminated.
- Challenge (Ch) - I see a challenge from S2 in lines 33 and 48 as he continues pressing S1 on how the math could possibly work out if work is set to zero. It is not just S2's words, but his aggressive *you must be crazy* tone of voice here (undetectable in the transcript) that lead me to mark both his question and statement as Challenges.
- Question (Qi) - The only question here is from S2 in line 33. As I have marked it as a Challenge, I can eliminate it as an Inquiring Question. The same question will not be both Challenging and Inquiring. This can be eliminated.
- Collaborate (Co) - I know S2 is not Collaborating with S1 as he is fully Challenging S1's ideas. However, both times S3 speaks it is to reaffirm the idea that work should be zero and continue on that path. Since S3 is building into one of the possibilities laid out by S2, S3 is Collaborating with S2 in creating the Issue.

I've identified that the main features of Issue creation in the example are Thoughtful and include Challenges and Collaboration. Figure 4.10 shows these highlighted in the diagram. Note they are also blue as they belong to the AI. Present features of the AI Issue creation will always be blue.

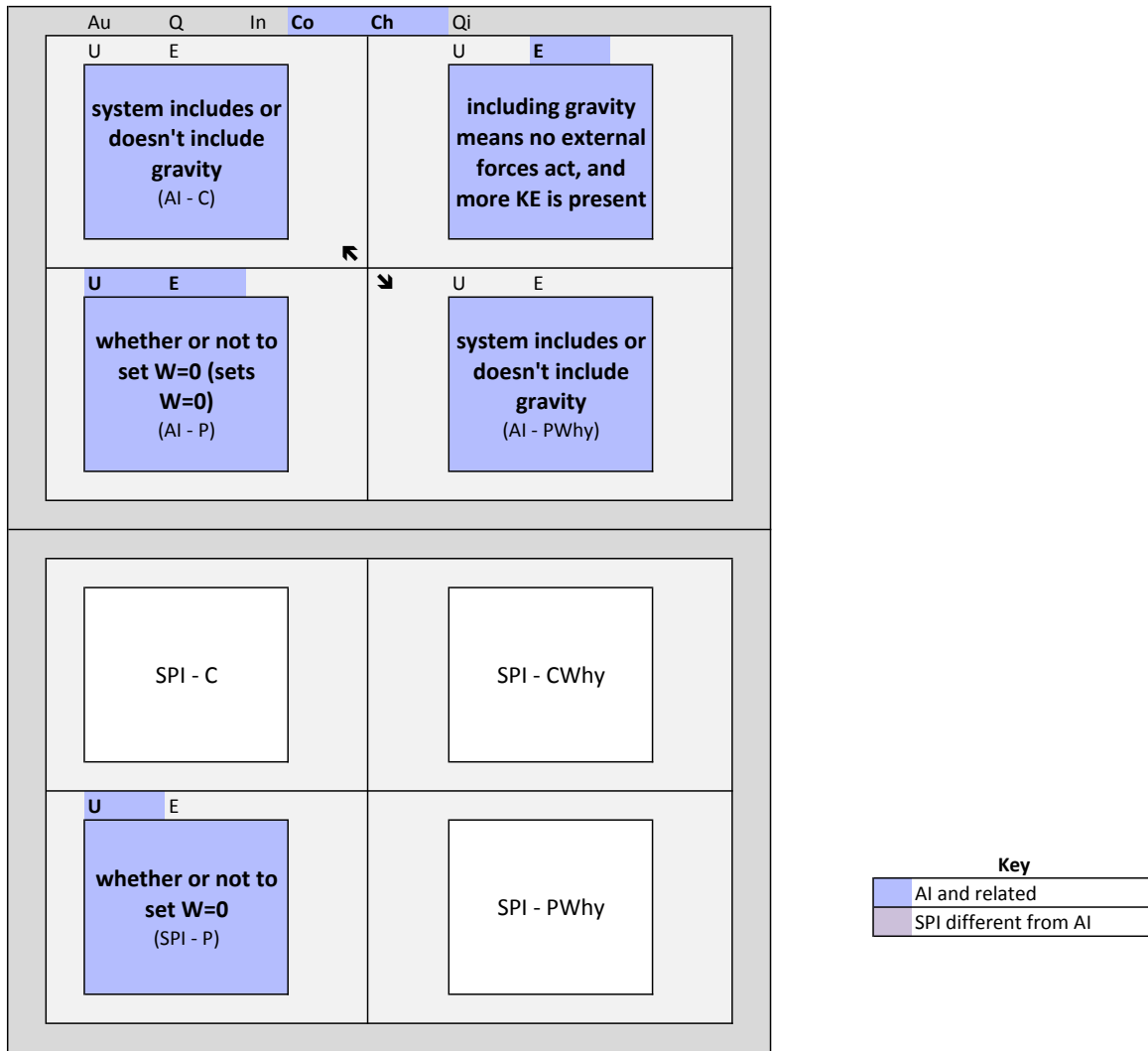


Figure 4.10: A third layer is added around the second layer in the example Issue diagram. This layer enwraps all components within each, the AI and SPI. This layer displays the creation features for the AI. The highlighted features - Co and Ch - are present in the example Issue.

Resolution Before the Interaction

One other feature stands out in the creation of the Issue and that is its **Resolution**. Certain components of the AI and SPI are sometimes Resolved before an interaction concerning them occurs. A resolution lets me know that an idea students have or a move students make has

changed before the interaction. A Resolution happens when the students have discussed an Issue and come to settle (actively and/or passively depending on the students) on the idea or move with which to go forward. The Resolution may be correct or incorrect (as judged by the researcher/physics expert). Slightly different rules are applied to the AI and SPI concerning their Resolution outside an interaction.

- Actual Issue components - This may only be considered Resolved if it is Resolved correctly as judged by the researcher/physics expert and accepted by the Issue creator.
- SPerceived Issue components - This may be Resolved through discussion and settling on an idea or move with which to go forward. The idea or move may be correct or incorrect as judged by the researcher/physics expert. Some students may still carry Uncertainty about the Resolution, but the group moves on.¹¹ This pertains to the students in general.

I note here that if a component of an Issue seems to disappear from the dialogue, it is not considered Resolved.

I'll add this feature into the diagram. I'll add it into each component respectively as any single component may or may not be Resolved. If the entire Issue is Resolved, then I will mark it Resolved in every component. Figure 4.11 shows this addition.

¹¹This term was changed from Resolved to Settling towards the end of coding for clarity. This is indicated by "Rs" in the diagram.

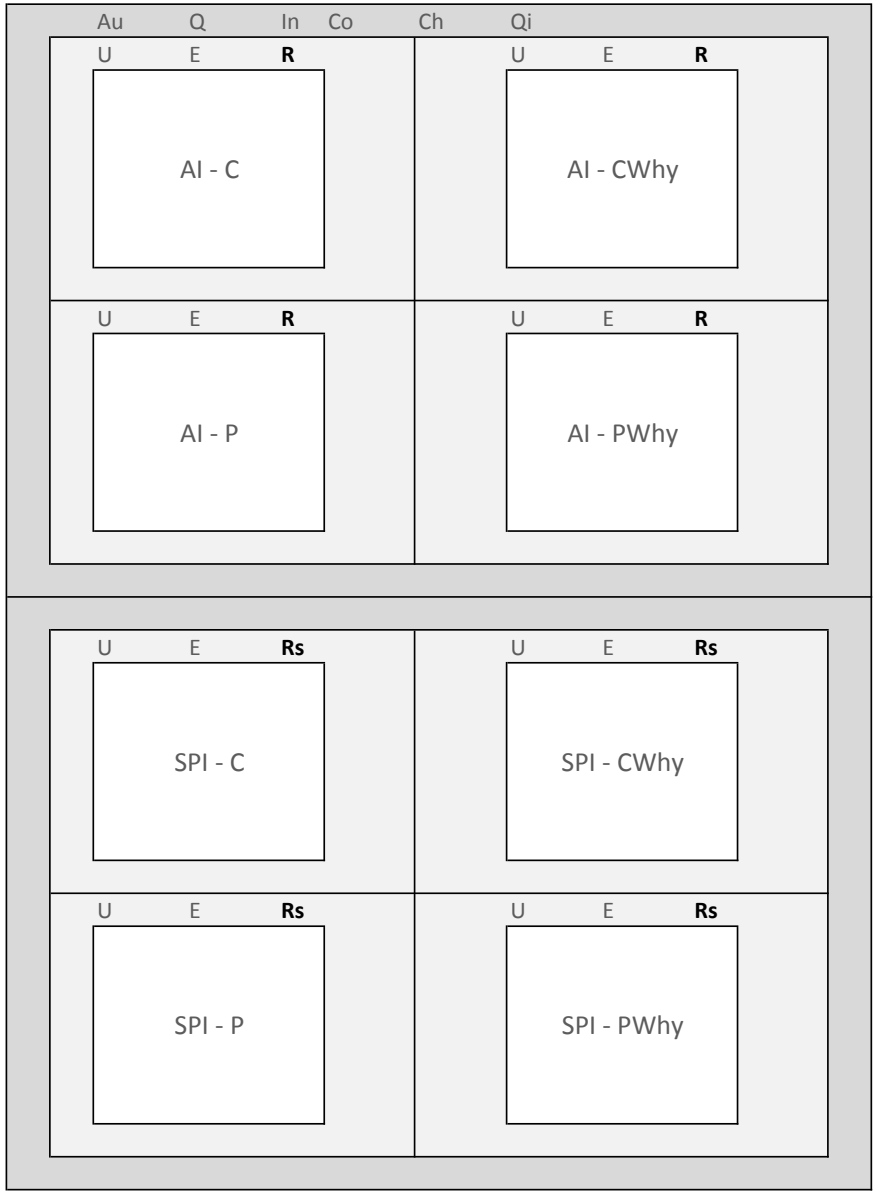


Figure 4.11: The Resolve feature (R) has been added above each component of the AI and SPI in the second layer of the diagram.

Example: Resolution Before the Interaction

I review the example to see if a possible Resolution lies somewhere before the interaction. Examining dialog for the AI - P component, I see that S1 initially states work to be zero

(line 33). This is not a Resolution, as there is no conflict about work yet to Resolve. Then he rethinks it (line 33) and proposes the possibilities for what to do with work (line 41). S3 decides that work should be zero and moves forward, S1 in tow, with that decision. Thus, the group Resolves their Issue of whether or not work should be zero by settling on setting $W = 0$. Since the students solidify their idea of incorrect physics content and make an incorrect move, this can not count as a Resolution for the AI - P. In fact, as stated above, it determines the presence of Error in the AI - P. However, it does that by being the Resolution for the SPI - P, since the SPI Resolutions do not have to be correct or even fully agreed upon. Thus, in this situation, I have the SPI - P Resolved incorrectly, creating an Error in the AI - P.

I now turn to the other components of the AI. I can skip PWhy/C as there is no Error or Uncertainty to Resolve. This leaves CWhy. I could make the assumption that S1 Resolves this component silently as he accepts the decision of $W = 0$ (line 52). But I feel that to be a bit presumptuous, lacking evidence and leading to an incorrect Resolution regardless. I really don't have evidence that the Resolution to $W = 0$ also Resolves the CWhy component. Nor do I have any extra evidence that S1 comes to Resolve CWhy. Thus, I must leave it unResolved. Figure 4.12 shows how this is marked in the diagram. Notice now that the Resolution feature for the SPI - P is marked bright red. This lets me know that the Resolution was incorrect. A bright green color (as shown in the key) would indicate a correct Resolution. All Resolution features will be marked either red or green as appropriate.

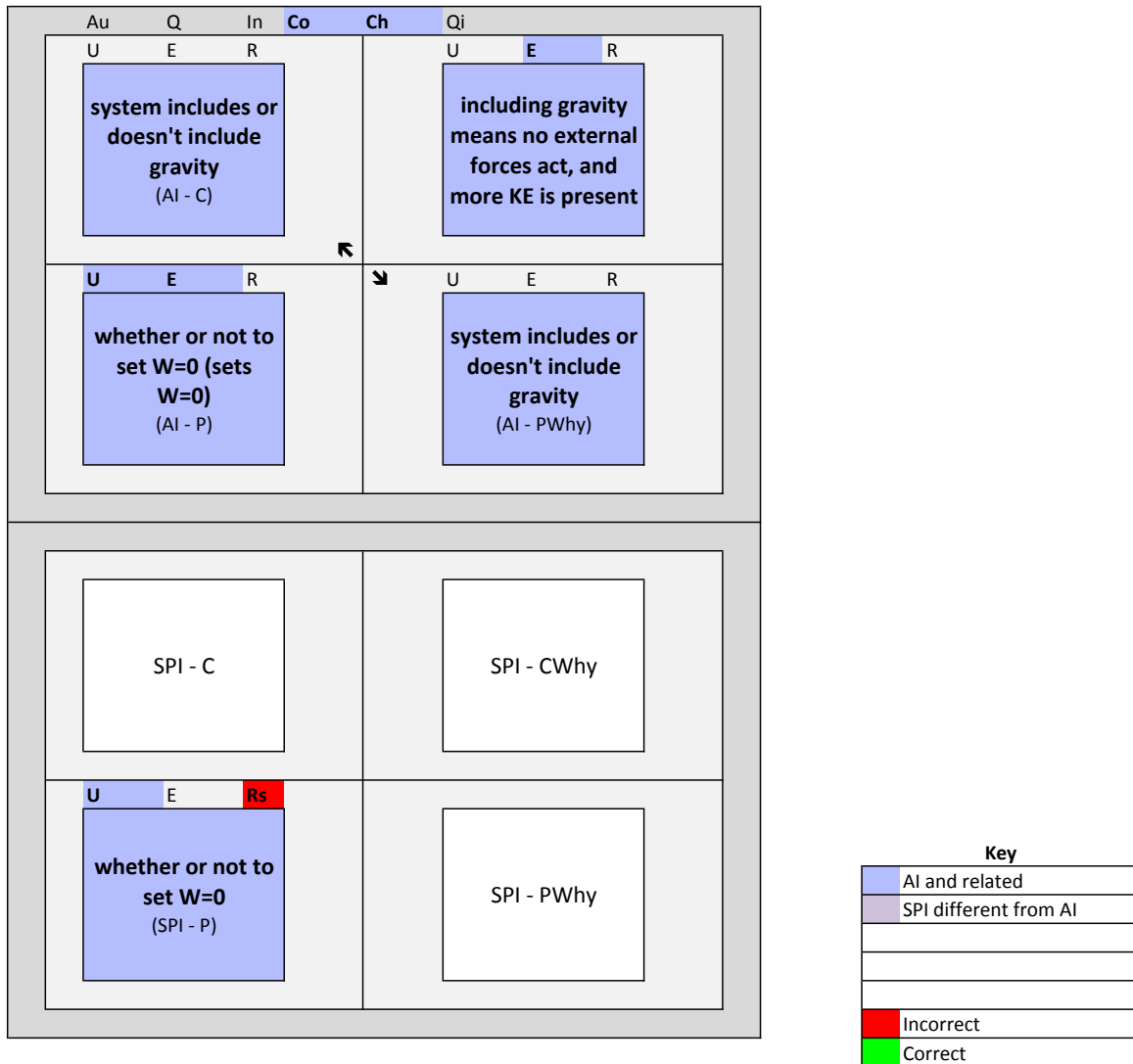


Figure 4.12: The Resolve feature (R) has been added above each component of the AI and SPI in the second layer of the example Issue diagram. It is highlighted red in the SPI - P component indicating an incorrect Resolution by the students before the interaction. The key now includes two more colors to distinguish between correct (green) and incorrect (red) Resolutions.

4.1.3 During an Interaction: The GTA's Focus and Address of the Issue

Once the Issue is created, I turn to the next piece of the data segment that covers the interaction between students and their GTA. I identify the relationships between the Issue, the physics

content expressed and moves made before the interaction, and what happens with the Issue during the interaction.

TAFocused Issue Contents (TAFI)

Since the interaction introduces the GTA to the Issue, I'll first determine how the GTA focuses on the Issue. To do this I identify the GTA's focal topic or the TAFocused Issue (TAFI). These are the contents that the GTA specifically focuses on and is identified directly through the GTA's verbal and written expressions. It also has the four possible components of the AI and SPI. The TAFI seems to arise in one of two ways:

1. The GTA has diagnosed the students as having a particular Issue and addresses it as such.
2. The GTA has not obviously diagnosed the students as having a particular Issue, but chooses to approach helping them through a particular topic.

Using those perspectives helps identify the contents of the TAFI, though I am not really concerned with how it appears. My main interest is to identify the contents to see how similar the AI and TAFI are. I have three options for similarity, met in different ways:

1. identical - The GTA focuses on exactly the Actual Issue the students are having.
2. nearly identical - The GTA focuses on exactly the Actual Issue the students are having but either more specifically or more generally than was present for the students beforehand. In this TAFI, the GTA adds (or omits) quite a bit of detail to that topic that was not present (or was present) for the students beforehand
3. different - The GTA's focus is different from the AI. This can happen as any combination of the following.¹²

¹²The GTA may also focus on the SPI. However, in my data, this either leads the GTA to then also focus on the AI or to focus on something different entirely. Thus, I do not identify a focus on the SPI as it is never the permanent focus.

- (a) The GTA's focus is still on the same general topic, but the perspective on that topic is quite different from the Issue created by the students. This may bring up different physics content or moves to be addressed.
- (b) The GTA adds physics content or procedural information to his/her focus that was not present for the students beforehand.¹³
- (c) The GTA omits physics content or procedural information from his/her focus that was present for the students beforehand.¹⁴

I will add the TAFI into the diagram and return to the example. Figure 4.13 shows their place in the diagram.

¹³The GTA does this by adding more details to a component than the students had in the AI or by adding components that were not present in the AI beforehand.

¹⁴The GTA does this by either leaving off details from a component that is otherwise the same as the AI, or by omitting a component altogether.

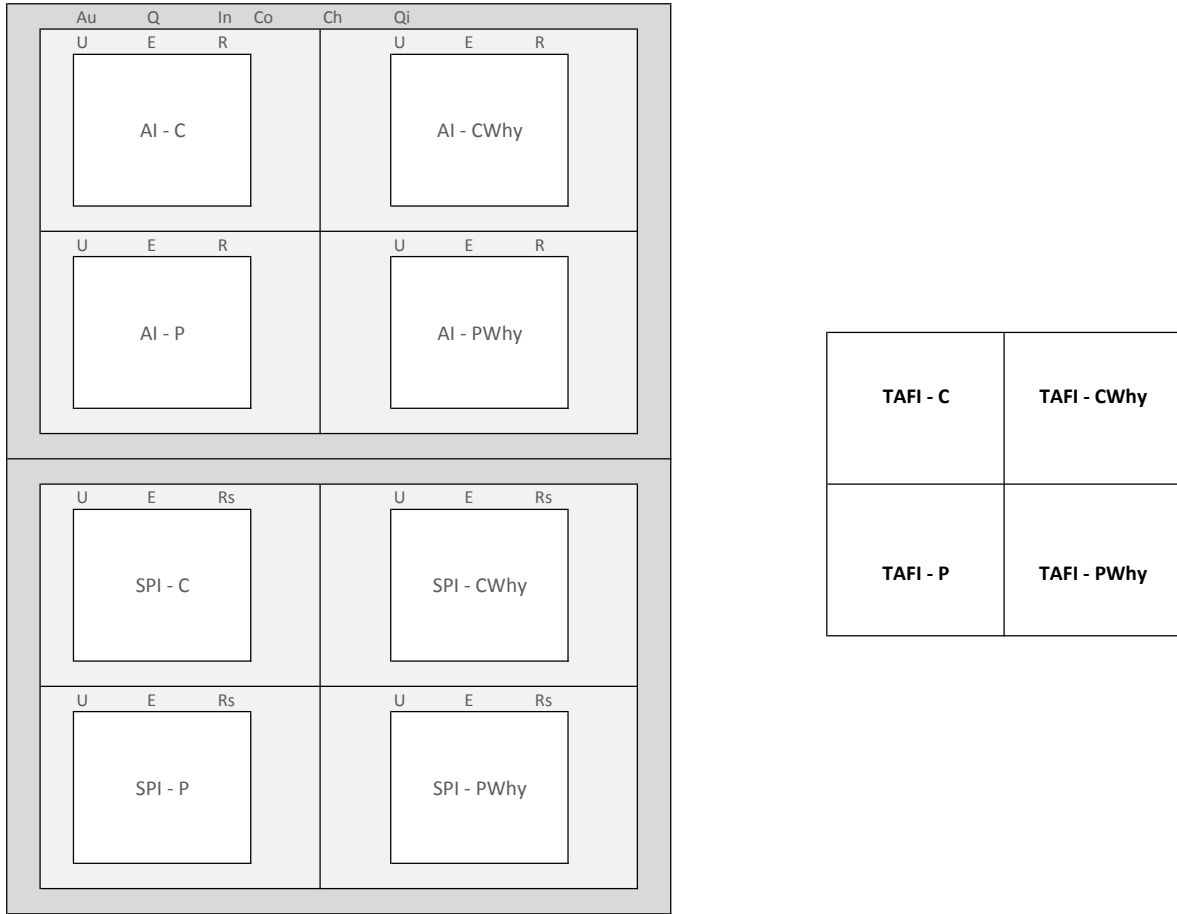


Figure 4.13: The TAFI components have been added to the diagram. They are placed off to the side to indicate they are only present during the interaction.

Example: TAFocused Issue Contents (TAFI)

Looking at the GTA's dialogue in the main example, let's pull out the TAFI.

- 53 **GTA:** Why is the work done zero?
- 54 **S2:** hmm?
- 55 **GTA:** Why is the work done zero?
- 56 **S2:** It's not?
- 57 **S1:** No. It's not zero.

58 **S3:** It won't be zero?

The GTA's contribution is brief but powerful. At first glance, the GTA asks a why question about a procedural move, indicating the desire for students to respond with reasoning about their move. I would initially think that this builds in a PWhy component for the GTA. However, looking further, I see that the students correct themselves, and the interaction ends with no further dialogue. In this light, the "Why?" question seems disingenuous, more of a correction to the students' move of making $W = 0$, than a true question of their reasoning. In fact, because the students do not answer the question directly, but simply correct their own move, it would seem they too have interpreted this question as a correction to their procedure, rather than a genuine question of their reasoning. From these observations I conclude that the GTA's question was in fact a focus on procedure only, giving the TAFI a single P component of identifying that students set $W = 0$. Building out the example diagram, I see the TAFI accounted for in Figure 4.14. Note that the blue color of the TAFI - P indicates it's matching the AI - P. If it was different, it would be colored orange (as seen in the key). If it was nearly identical¹⁵, it would have been both orange and blue. Note also that the absence of the other three components that are present in the AI is very apparent in the diagram. At a glance, I can see that the GTA has not focused on the rest of the AI. I consider these components missed by the GTA.

¹⁵This is a TAFi in which the GTA adds more details to a single component than the students had in that component of the AI, or the GTA leaves off details from that component that the students had in the AI.

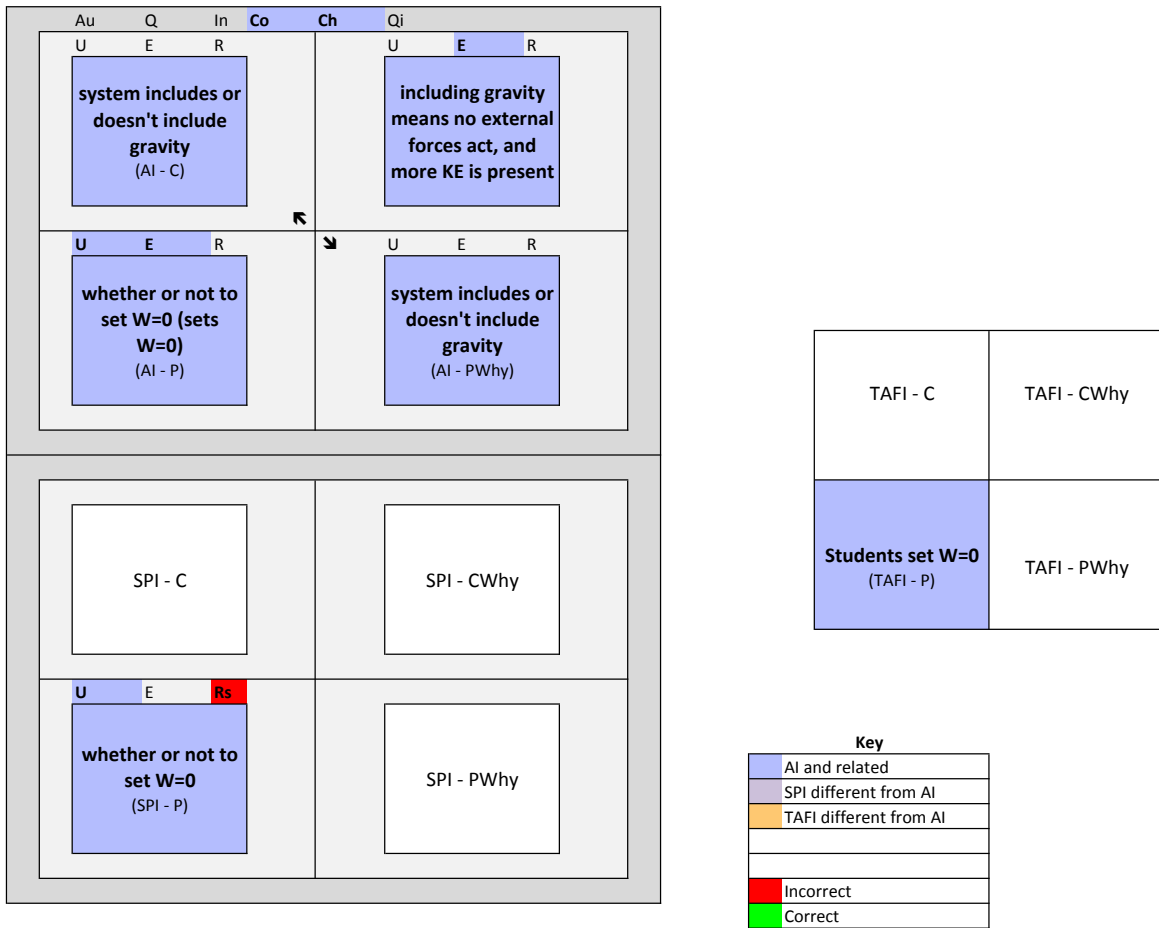


Figure 4.14: The TAFI components have been added to the example Issue diagram. The contents of each component are filled in according to their presence in the example. Blank components remain uncolored with a label only. The TAFI is blue, indicating it is the same as the AI. The key now contains a new color (orange) to differentiate between the AI and TAFI, should the TAFI ever be different from the AI.

Student Response to TAFI

Continuing with the TAFI, several features emerged in how the students responded to the GTA's focus. These features show how students related to the physics content and moves of the TAFI. In identifying these features, I first attempted to see how they fit with each individual component of the TAFI. However, the TAFI is often too concise and quickly stated to identify whether or not students are responding to a particular component or the entire focus. At times I could pick this out of the content of students' statements. But often I was left too uncertain. Since student responses could not easily be fit with each component, I decided to only apply them to the whole TAFI. No features will be identified for individual TAFI components. These features are not mutually exclusive as any and all could appear at some point in an interaction. The students could:

- **Go Along (Go)** - Students focus along with the GTA on whatever the GTA focuses on, but they do not really engage more than that. They are simply along for the ride.¹⁶ This pertains to the students in general.
- **Get It (Get)** - Students express an understanding of what the GTA is focused on, as if they are on the same page. This involves more engagement than the Go feature but does not necessarily mean students express a fully correct understanding. This pertains to the students in general.
- **Redirect (Redirect)** - Students attempt to get the GTA to focus on a different topic, usually more related to their AI or SPI. This pertains to any particular student.
- **Rectify (Rectify)** - Students attempt to merge information from the TAFI into a previous idea. This pertains to any particular student.
- **Resolve (R)** - Students are able to understand whatever correction comes with the TAFI and move on in their solution construction after this correction. The TAFI is only Resolved

¹⁶This feature was present in every single data segment except the main example here. As it provided no additional way to compare the data, the Go feature was omitted in the results section.

if the students demonstrate some understanding of its Resolution. This pertains to the students in general.

Figure 4.15 shows these features built into the diagram. Any features present will take on the same color as the TAFI. If some components of the TAFI are the same and others are different, the features present will pertain to those components that are different, and thus will be colored orange showing that difference. However, Resolve will take on bright green if present.

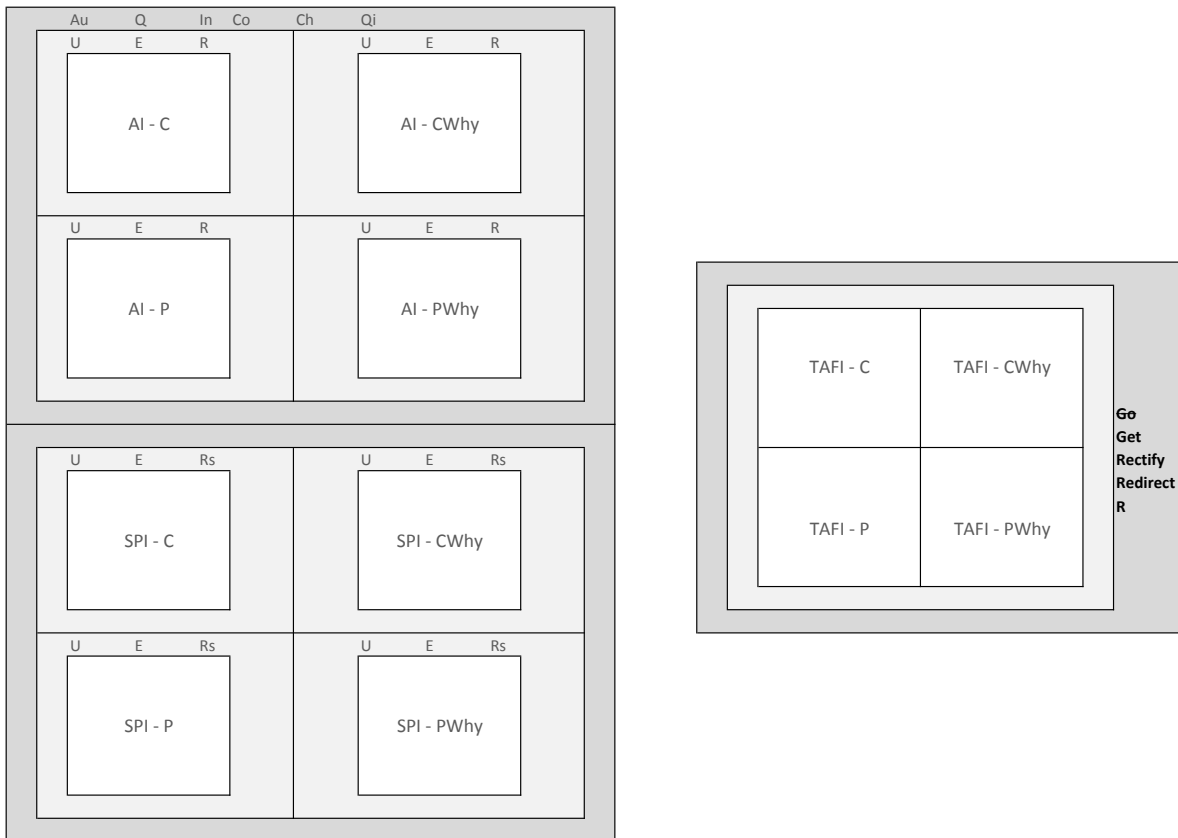


Figure 4.15: A second and third layer have been added around the TAFI. No features pertain to the specific components of the TAFI, so the second layer is blank. The third layer contains the features that concern the TAFI as a whole - Go (crossed out in the diagram as it is no longer used¹⁶), Get, Rectify, Redirect, and Resolve (R).

Example: Student Response to TAFI

I identify the presence or absence of these features in the example.

- Go - S2 and S3 do not seem so much to go along as to clarify that they are in fact incorrect (lines 56 and 58). They do not refute anything, they simply question and are not given any time in the brief interaction to go along. S1 has one line, and that line corrects their mistake, identifying exactly what the GTA is focused on (line 57). He goes along by default, but the evidence in his line points to much more than simply going along. Since there is no further dialogue to examine, I eliminate this feature.
- Get - After the GTA asks the question again, and S2 questions the students' correctness, S1 jumps in very demonstratively with the official correction (line 57). S1 has seen that the GTA is correcting the group, and that they were wrong in setting $W = 0$. His language and confidence are evidence that he Gets the GTA's intent and focus. Thus, this feature is present.
- Redirect - All students' expressions stay exactly on the TAFI, never attempting to get the GTA to talk about something different. This feature can be eliminated.
- Rectify - While S2 and S3 ask questions clarifying the GTA and their own correctness, they do not specifically bring up a previous idea and attempt to fit this information into it. Simple corrections such as these are not same as students rectifying their ideas. Similarly, S1's correction of the students' Issue does not mean he is rectifying an earlier idea. He is simply changing a move.
- Resolve - S1's immediate correction of the group's mistake shows that the TAFI is Resolved. This is a change of content from what developed before the interaction.¹⁷

Figure 4.16 shows the diagram's inclusion of these features for the example. Note the feature(s) present gets the same color as the TAFI, blue, but the Resolution is bright green. In this case,

¹⁷Due to the TAFI - P, SPI - P, and AI - P being the same, this is also a Resolution for the SPI - P and the AI - P. I'll mark these as Resolved and return to them later.

the same line governs Get and Resolve, making them seem similar. However, they are not the same feature, nor are they necessarily governed by the same expressions. They can, at times, be mutually reinforced by the same expressions.

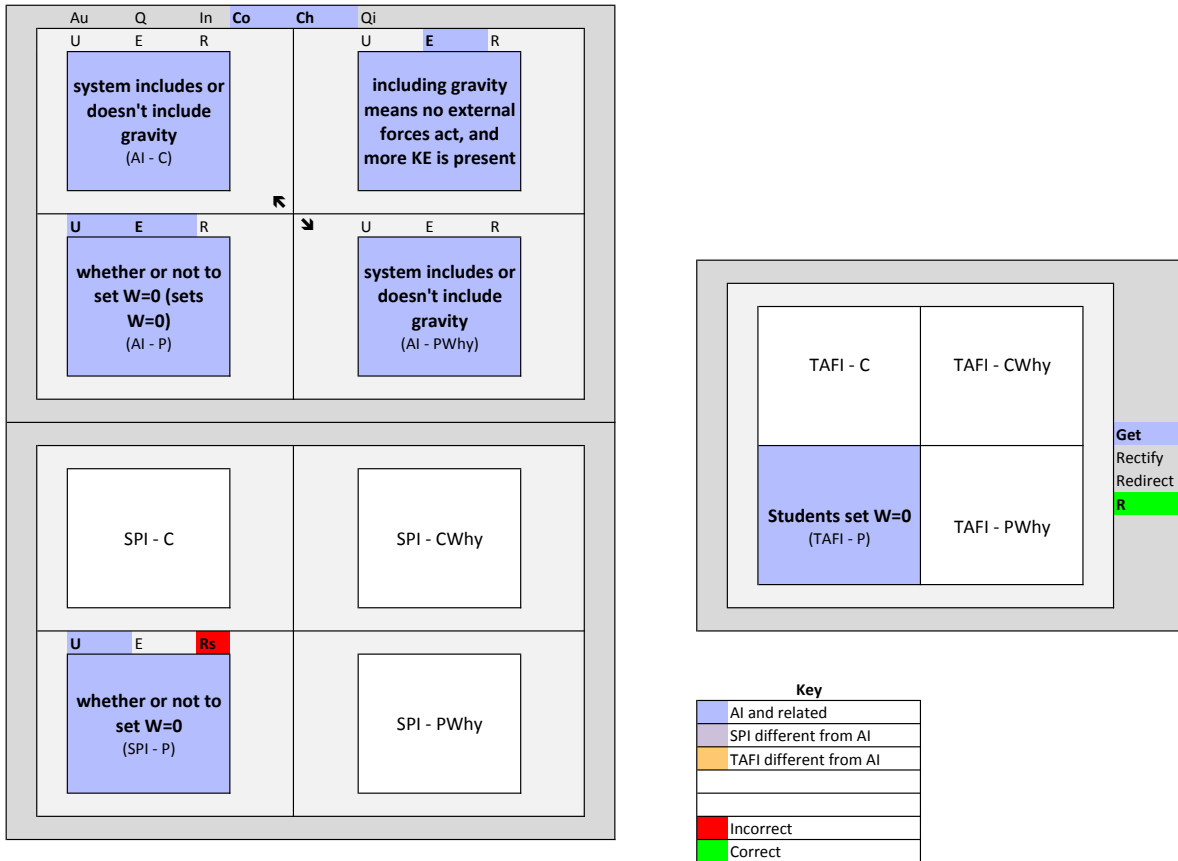


Figure 4.16: A second and third layer have been added around the TAFI of the example Issue diagram. No features pertain to the specific components of the TAFI, so the second layer is blank. The third layer contains the features that concern the TAFI as a whole. The features present in the example Issue - Get and R - are highlighted. Get is blue to match the TAFI. R is green to indicate a correct resolution of the TAFI.

Addressing the Issue

I return now to the AI and the SPI and look to see if and how those are **Addressed** in the interaction. The features that emerge detail the connection between the interaction and the

Issue components developed before the interaction. The Address of the AI and SPI occurs by component, rather than the Issue as a whole. This allows me to specify what within the general Issue topic is really being targeted. If the entire Issue is Addressed, all components will be marked as such. The Address of the Issue pertains to any students and/or the GTA. I identify two different perspectives from which to determine whether a component is Addressed:

- The Issue component may be Addressed directly if the intent of the interaction is towards the Issues and the information provided in the interaction pertains specifically to the Issue
- The Issue component may be Addressed indirectly if an interaction concerning a different topic still provides help or useful information for the current Issue
- Note: The Issue component may not be Addressed at all. This can happen when an Issue is introduced by someone, but then ignored rather than dealt with during the interaction

I add to the framework only whether or not each particular component of an Issue is Addressed and not whether it is direct or indirect. The use of direct and indirect helps focus a bit more on identifying whether or not the Issue has been Addressed, but is not relevant other than that. I will note when an interaction is intended for some other problem or Issue and lends information to the present one.

Additionally, I examine how the component is being Addressed: **Procedurally**, **Conceptually**, or both. These also pertain to any students and/or the GTA. I'd anticipate Procedural talk is used to Address a P component but am interested to know if Conceptual talk is also used, and vice versa. The two kinds of dialogue carry the following definitions:

- **Conceptual (Conc)** - concerning conceptual ideas of either physics or the physical situation or concerning the interpretation of a problem statement
- **Procedural (Proc)** - concerning only moves to be made or specific instructions to be followed when constructing a solution

Finally, I wish to know whether each component of the Issue has been **Resolved (R)** by the end of the interaction. This identifies whether the students have made changes to the physics content they've expressed or moves they've made. The Resolution may happen for any component of either the AI or SPI. To determine Resolution during an interaction, two criteria must be met.

- The Resolution is correct as judged by the researcher/physics expert, and
- The component is considered Resolved in the eyes of the Issue creator.

If both of these criteria are met, a component is considered Resolved during the interaction. If one of these is not met, the component is not Resolved. However, there are times in which the component does not seem Resolved for the Issue creator, but is obviously Resolved for other students in the group. In these cases, I can call the Issue **Functionally Resolved (Rf)**. This allows for the fact that the students will be able to use the Resolution going forward, even if the Issue is not yet Resolved for a particular group member.

In other cases, there may not be a Resolution at all, but there might be a **Shift** in the Issue component. If they had made an Error before, they may not fully Resolve it, but begin a correction and become Uncertain about it. This would be featured as a Shift from Error to Uncertainty. Likewise, students who were initially Uncertain about a component of their Issue, might Resolve it incorrectly, Shifting from Uncertainty to Error. This pertains to the students in general.

Note: Functional Resolutions and Shifts need only apply to the AI. I'll take a quick look at the possible SPIs to see why this makes sense.

1. SPI nonexistent - Any realization of an Issue emerges as the AI or TAFI and so Functional Resolution, Shift, or other appropriate feature will be applied to those instead
2. SPI same as AI - Any Functional Resolution is the same as for the AI, so need only be present in the AI

- SPI different from AI - There was no emergence of students Functionally Resolving only the SPI, and as this kind of SPI is merely a feature of the more important AI, need not contain these features for completion.

Figure 4.17 shows the diagram with these latest features added in.

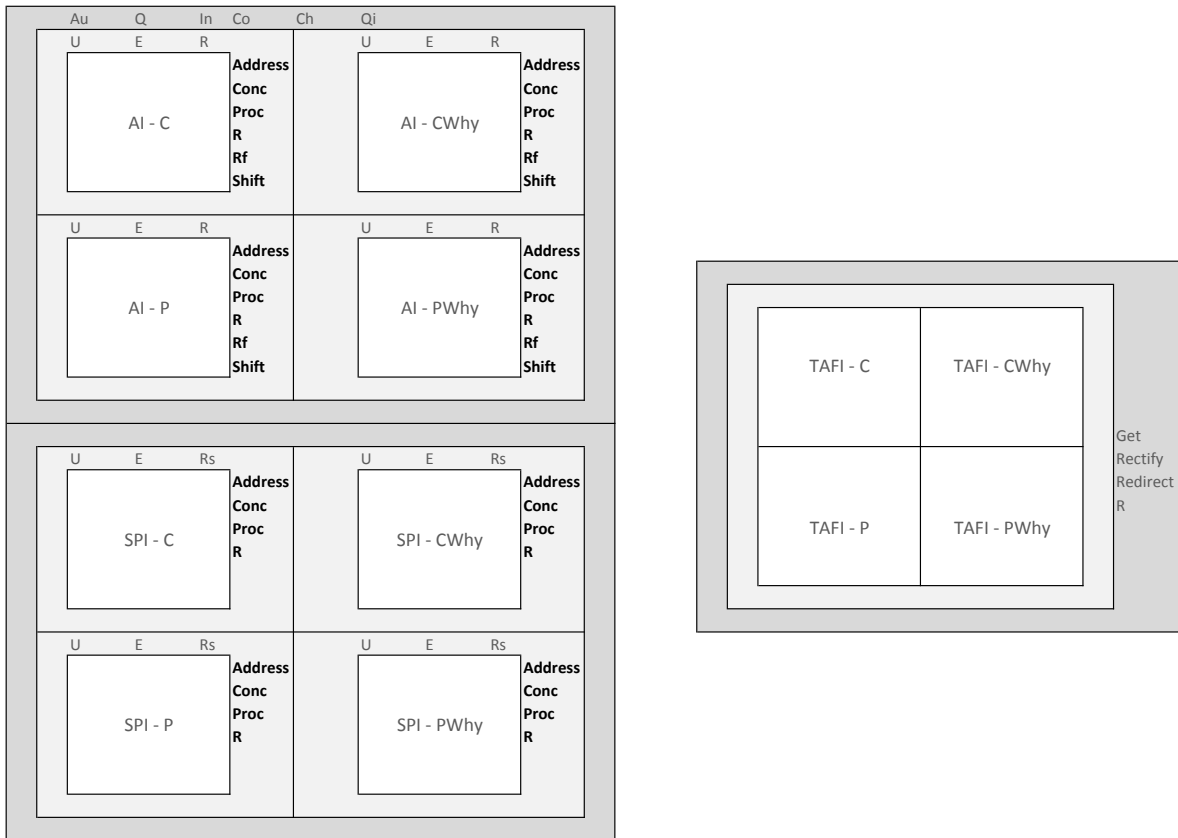


Figure 4.17: The Issue Address features - Address, Conceptual (Conc), Procedural (Proc), Resolve (R), Functionally Resolve (Rf), and Shift - have been added to the side of each component of the AI and SPI in the second layer of the diagram.

Example: Addressing the Issue

Looking at the example, I'll first identify which components are Addressed, then how they are Addressed and Resolved. The example interaction is quite short, so there will be no mystery

here.

- P - Whether or not work should be zero is Addressed. Thus, the P component is Addressed. Since it has the same contents as the SPI, SPI - P is also Addressed.
- PWhy - As discussed above, the response from the students to correct their mistake followed by the immediate departure of the GTA shows that PWhy is in fact not Addressed.
- C - Since C is the same as PWhy, C is also not Addressed in this interaction.
- CWhy - This component deals with external forces and the amount of kinetic energy. Neither of these topics enters the interaction at all and so neither is Addressed in the interaction.

I see here that only P is Addressed in this interaction. To look at how it is Addressed, I look at how it is talked about. Dialogue that deals with the moves made would be Procedural, while dialogue concerning the physics behind those moves would be Conceptual. Looking at the dialogue, I see only a discussion of correcting work from zero to not zero. I do not see any discussion of physics or the physical situation supporting this component. Again, the GTA's question may have led to a more Conceptual discussion if answered differently. But in this case, only Procedural talk took place. Thus, only Procedural talk Addressed this component.

Finally, I look at whether or not this component was Resolved. As mentioned above, a Resolution in the TAFI in this case is also a Resolution for this component since they have the same contents. However, even if I do not look at the TAFI but just at the dialogue, I see again that S1 corrects the students from a work of zero to a work that is "not zero" (line 57), correctly changing his view of the content. There is confidence in his voice in saying this, and it is the correction needed for this component. Thus, this component is Resolved. As mentioned previously, a Resolution here also means a Resolution for the SPI - P as the contents of these components are the same. Figure 4.18 shows the example diagram with these features added and highlighted appropriately. I note they are mostly blue to match their respective components, except for R which is green to indicate a correct Resolution.

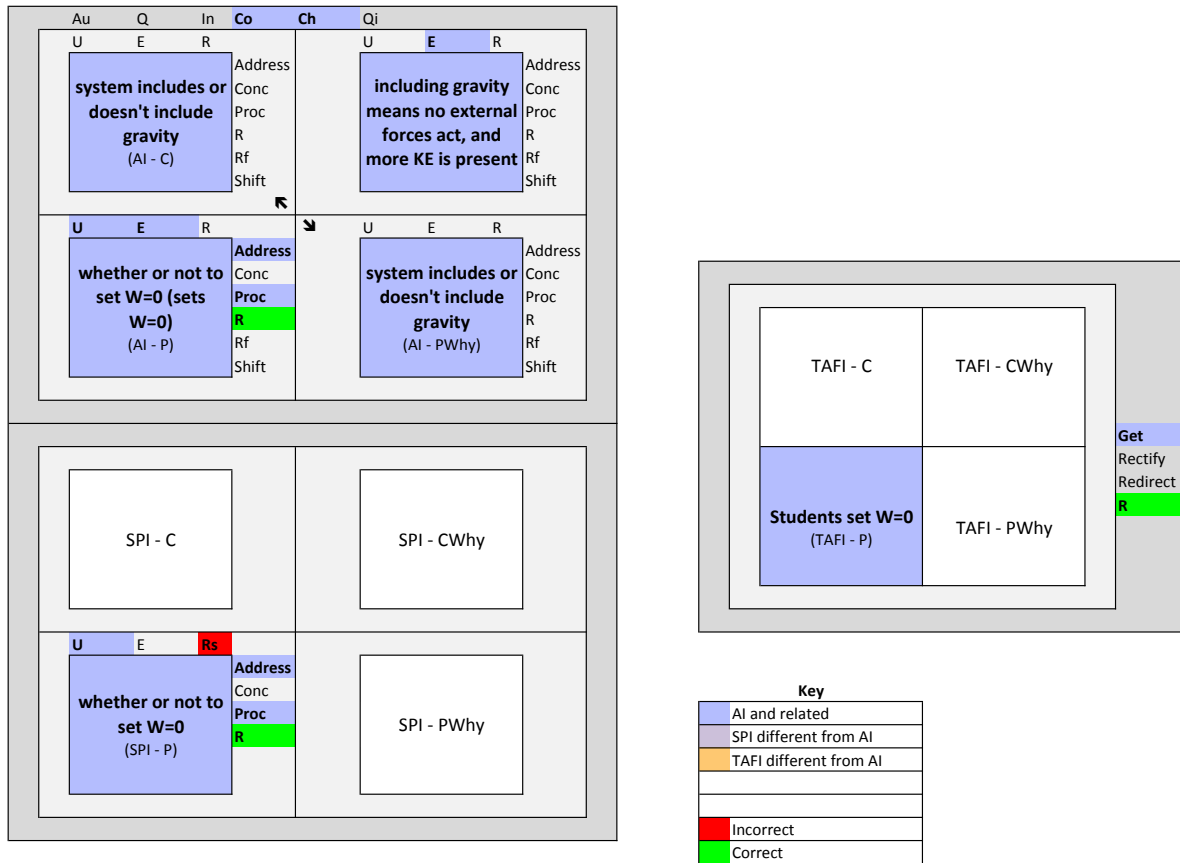


Figure 4.18: The Issue Address features have been added to the side of each component of the AI and SPI in the second layer of the diagram. Features are highlighted next to components in which they are present - AI - P and SPI - P - in the example Issue. Features are blue in accordance with their respective components. R is green indicating the component is resolved correctly.

Issue Beginning the Interaction

With an understanding of the how Issues are Addressed within an interaction, I return to the beginning of the interaction to note which of these Issues - AI, SPI, TAFI - if any, began the interaction. I identify this to determine whether the central Issue, the AI, is the beginning focus of the interaction, or whether it is something else.

In addition to the three possible kinds of Issues beginning the interaction, there could be some other kind of dialogue that begins. For instance, the GTA might come in and immediately

praise students before Issues are brought up. Or the beginning of the interaction might concern an Issue, but not the Issue that is a part of the particular data segment under examination. This feature does not pertain to any person in particular, but simply to the dialogue expressed at the very beginning of the interaction.

Adding this feature to the diagram also marks the beginning of the outermost layer of the diagram. This layer is reserved for features that do not pertain to any particular individual Issue but to all of them more generally. Figure 4.19 shows the outer layer added with this feature. This feature is specifically added in the middle column of the outermost layer to avoid any possible connections with specific kinds of Issues as well as to allow the eyes to scan quickly between the outer layer feature and any specific Issue. All further outer layer features emerging during the interaction will also be added in this center column.

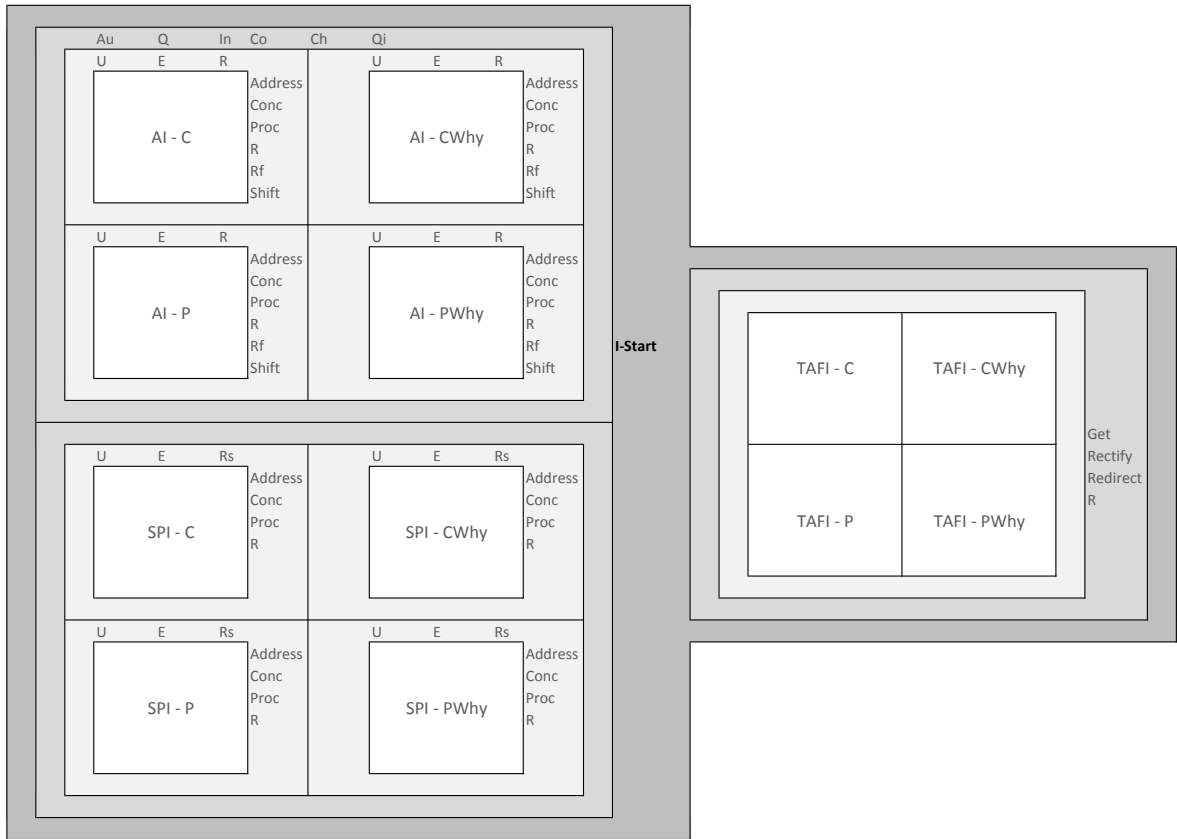


Figure 4.19: The fourth and outermost layer is added enwrapping the AI, SPI, and TAFI. This layer contains features concerning the Issues most generally. I-Start is added here to indicate the Issue beginning the interaction - AI, SPI, TAFI, or other.

Example: Issue Beginning the Interaction

Looking at the example, I see that line 53 shows the GTA beginning the interaction with a question about the work being zero. This pertains to all three kinds of Issues, since they are all the same. In these cases, I use a hierarchy to determine which Issue the interaction was begun on - AI, then SPI, then TAFI. Thus, this interaction started on the AI. Figure 4.20 shows the example diagram with the outer layer built in and the feature highlighted. Note this feature will carry the same color as its label: in this case, blue.

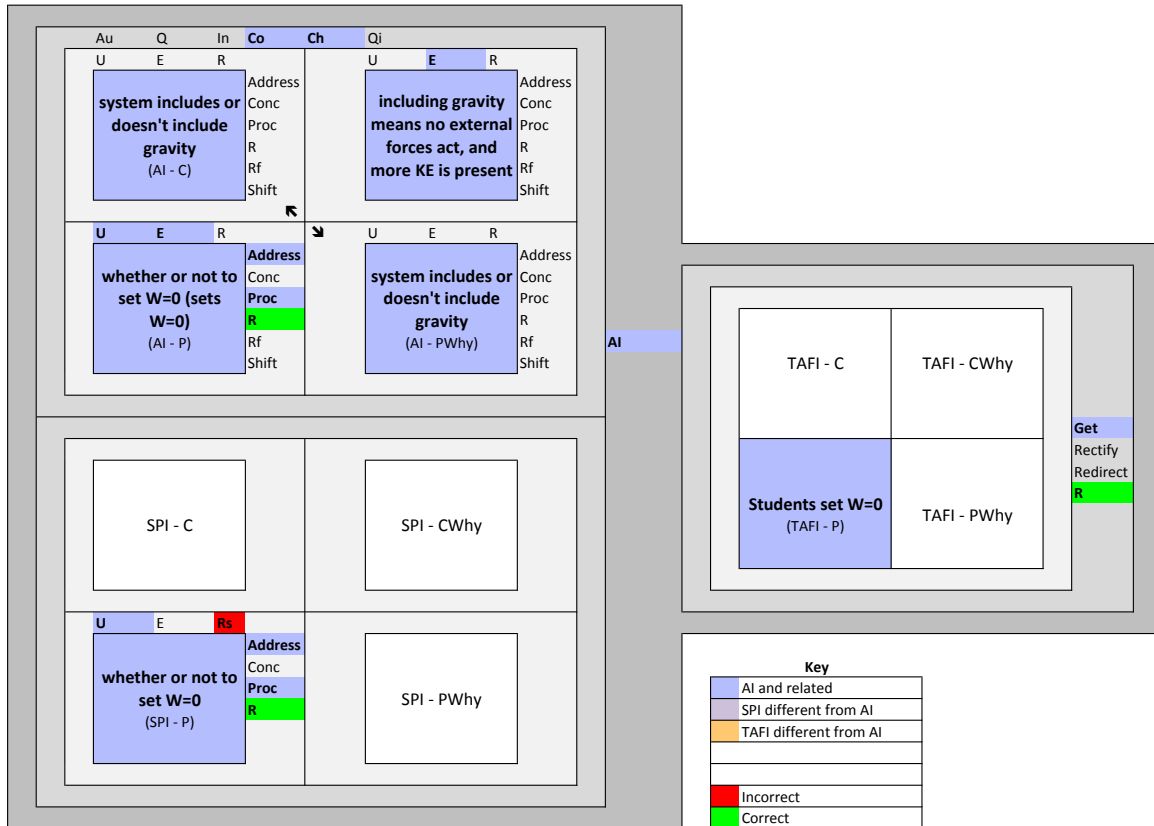


Figure 4.20: The fourth and outermost layer is added to the Issue example diagram. This layer contains features concerning the Issues most generally. AI is added as the Issue that began the interaction. It is colored blue in accordance with its components.

Other Possible Student Actions

In addition to Addressing and Resolving specific components of an Issue, several other features emerged concerning what students do during an interaction. These relate to the Issues more generally, but no single Issue specifically. They do tell, however, whether students' procedural moves change during an interaction.

- **Move** - Students may move forward with their solution without any reference back to the Issue after a Resolution has been reached. This pertains to the students in general.
- **Restart** - Students may restart all or a large piece of their solution after a Resolution has been reached. This pertains to the students in general.

- **Demonstrate (Demo)** - Students may demonstrate an understanding (or lack of understanding) by mentioning or using info from the interaction after they have Moved forward on or Restarted their solution construction. This pertains to any particular student.
- **Feel** - Students may express feelings of content or discontent towards the interaction and help received. This pertains to any particular student. (While I am not interested in most aspects of affective domain, the explicit expression of feelings can clue me in to how students are receiving the interaction and help from the GTA as well as their own confidence in the physic content and moves addressed during the interaction.)

The first two features - Move and Restart - can only emerge after a Resolution or Functional Resolution during the interaction. The third item - Demo - only emerges after one of the first two. This was a design choice. Students may Demonstrate some understanding of the topic at any point during the interaction, but I am interested in whether they are expressing some understanding after all is said and done, not while the Issue is being Addressed. The fourth may happen at any time but tends to appear at the end of the help with an Issue.

Figure 4.21 shows the diagram with these features added in. They are added to the outermost layer as they do not pertain to any particular Issue, but more generally to all of them. As mentioned above, they are also added to the central column of the outermost layer.

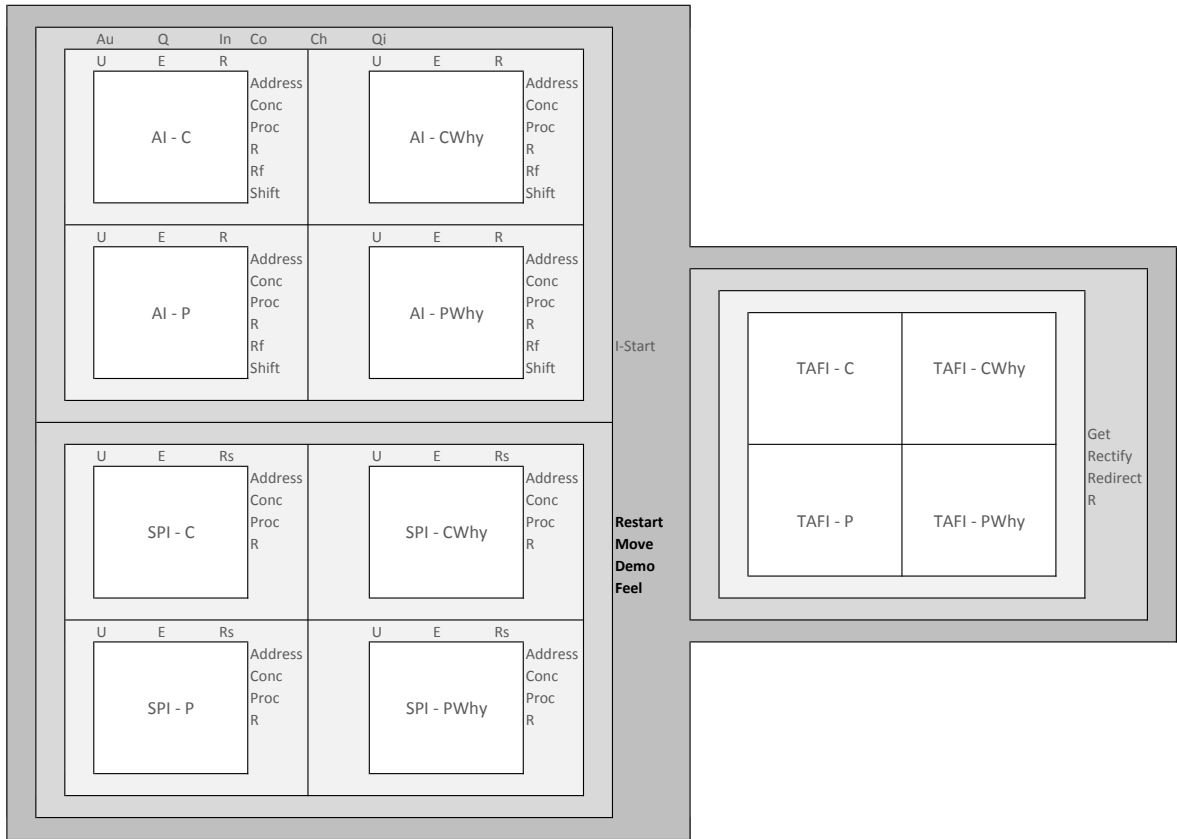


Figure 4.21: The list of other actions students may do during an interaction - Restart, Move, Demo, Feel - is added to the outermost layer.

Example: Other Possible Student Actions

I can now analyze the interaction dialogue for the possible presence of any of these features.

- Move - Lines 56 - 58 of the interaction, after which it is over, simply point to a repetition in statement and question form that the students assignment of zero to work is incorrect. It is only after this correction that they can Move forward. Since the interaction ends with the correction, there is no moving forward here.
- Restart - For the same reasons stated above, students do not Restart any part of their solution during the interaction. This, too, can be eliminated.
- Demonstrate (Demo) - This must happen after one of the first two features above. Since

those are both absent, this one is as well.

- Feel - S2 and S3 sound a bit confused, but I do not attach emotion to confusion alone. They do not specifically emote anything in particular. And while S1 states the groups' correction with a bit of resignation in his voice, he too does not express any clear Feelings. This can be eliminated.

As none of these features exist in the example, I'll skip reviewing the current diagram for now and move on.

4.1.4 Post-Interaction: Issue Resolution and Other Student Actions

Students may take one or more courses of action in regards to the Issue and the interaction once the interaction is over. The features emerging here reveal what the students are doing with the contents of their Issue after the interaction. The interaction is the catalyst that leads to these courses of action.

Resolving the Issue

If an Issue has not yet been Resolved, students may **Resolve** it (Actual and/or SPerceived) after the interaction. Once again, the resolution features let me know if changes have been made to the physics content expressed or moves made by the students. A Resolution here carries the same definition and requirements as a Resolution before the interaction does. I've repeated those below for continuity.

Resolutions are component specific. A Resolution happens when the students have discussed an Issue and come to settle (actively and/or passively depending on the students) on the idea or move with which to go forward. The Resolution may be correct or incorrect (as judged by the researcher/physics expert). Slightly different rules are applied to the AI and SPI concerning their Resolution outside an interaction.

- Actual Issue components - This may only be considered Resolved if it is Resolved correctly

as judged by the researcher/physics expert and accepted by the Issue creator.

- SPerceived Issue components - This may be Resolved through discussion and settling on an idea or move with which to go forward. The idea or move may be correct or incorrect as judged by the researcher/physics expert. Some students may still carry Uncertainty about the Resolution, but the group moves on.¹⁸ This pertains to the students in general.

I note here that if a component of an Issue seems to disappear from the dialogue, it is not considered Resolved.

Additionally, a component may be Functionally Resolved or not Resolved but Shifted after the interaction. These definitions are the same as mentioned above and restated here for continuity. They only apply to the AI.

- **Functional Resolution (Rf)** - The Issue remains unResolved for the Issue creator but is Resolved enough for other group members to Move forward with any corrections and continue solution construction.
- **Shift** - With the influence of the interaction, components that originally contained Error now only contain Uncertainty and a vice versa.

Figure 4.22 shows these pieces added into the diagram. Note that they are added under each component, indicating that they appear after the interaction is over.

¹⁸This term was changed from Resolved to Settling towards the end of coding for clarity. It remains R for Resolved in the diagram.

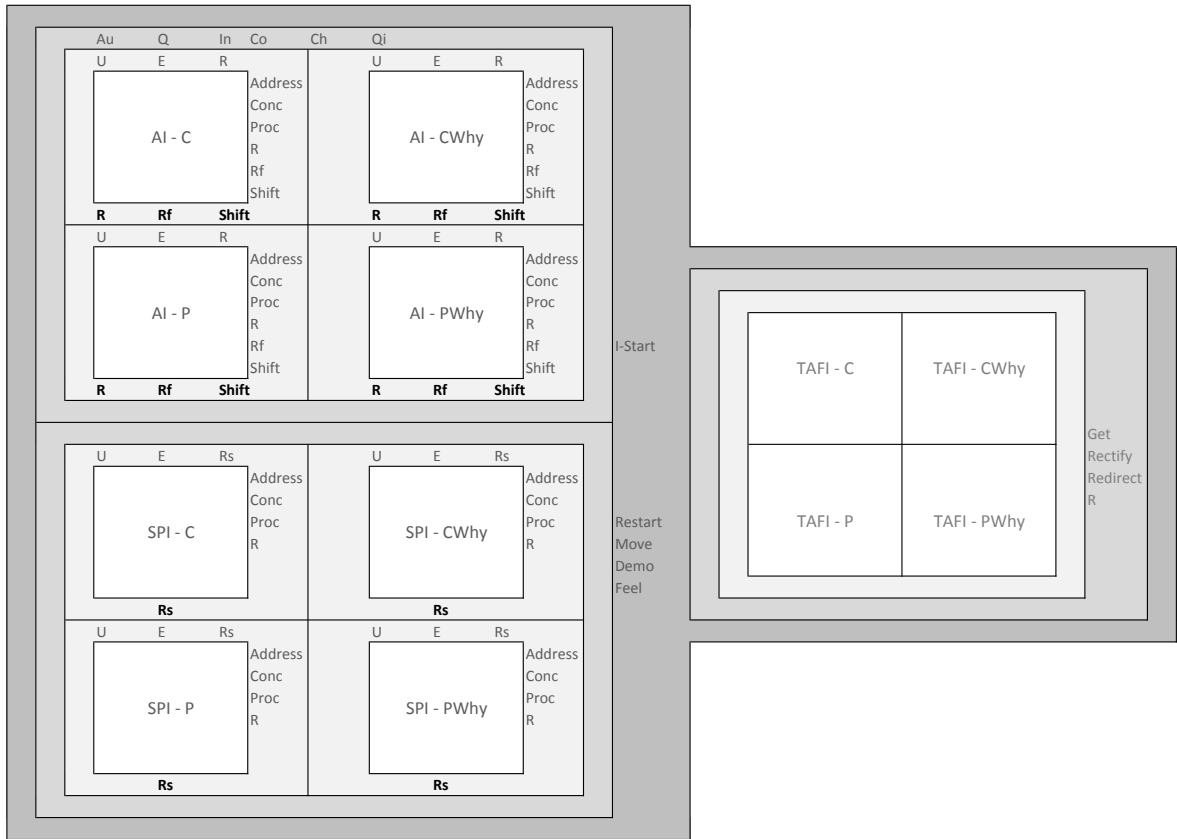


Figure 4.22: Features concerning the resolution of the Issue after the interaction - R, Rf, Shift - are added accordingly along the bottom of the second layer of each component of the AI and SPI.

Example: Resolving the Issue

As shown above in the example, the AI - P component was Resolved during the interaction. Once Resolved, a component can not be re-Resolved, and so I have no need of examining it after the interaction. PWhy/C still do not need to be Resolved. However, the CWhy component remains unResolved, and it is possible further discussion afterward might Resolve it. I'll examine the dialog to see if a Resolution comes out.

59 **S2:** Work equals... I can't remember the formula for work.

60 **S1:** No, work - Yeah, work is just, um, F_x times Delta x plus F_y Delta y plus, F_z Delta
 61 z , all added together ($F_x * \Delta x + F_y * \Delta y + F_z * \Delta z = W$).

No further discussion of the CWhy component is had. Students simply continue with defining work. Thus, the CWhy component remains unResolved. The diagram, then, remains unchanged and so I'll refrain from showing it again here.

Other Possible Student Actions

In addition to possible Resolutions or Shifts within the specific components of an Issue, several other features emerged in regards to what students might do after an interaction that could be related back to the interaction and Issues more generally. Most of these are the same as defined in the above section during the interaction and are reprinted here for continuity.

- **Move** - Students may move forward with their solution without any reference back to the Issue. This pertains to the students in general.
- **Restart** - Students may restart all or a large piece of their solution. This pertains to the students in general.
- **Discuss (Disc)** - Students may continue a discussion begun in the interaction. Specifically, the GTA may set students discussing a particular path and they continue to do so after the interaction. This pertains to the students in general.
- **Demonstrate (Demo)** - Students may demonstrate an understanding (or lack of understanding) by mentioning or using info from the interaction. This pertains to any particular student.
- **Feel** - Students may express feelings of content or discontent towards the interaction. This pertains to any particular student. (again, while I am not interested in most aspects of affective domain, the explicit expression of feelings can clue me in to how students are receiving the interaction and help from the GTA as well as their own confidence in the physic content and moves addressed during the interaction.)

I add these into the diagram in the outermost frame as they do not pertain to any Issue in

particular, but to all of them collectively. Figure 4.23 shows this. Not only are these just at the bottom, but I've shifted them to the right in an extended arm of the outer layer. I do this only for clarity. Having them just below the SPI was not eye-catching enough to associate them with the entire outer layer afterward. Shifting them over made it more believable that these features were, in a sense, the end of the line in the data segment - the lower right being more inline with the end of a reading page.

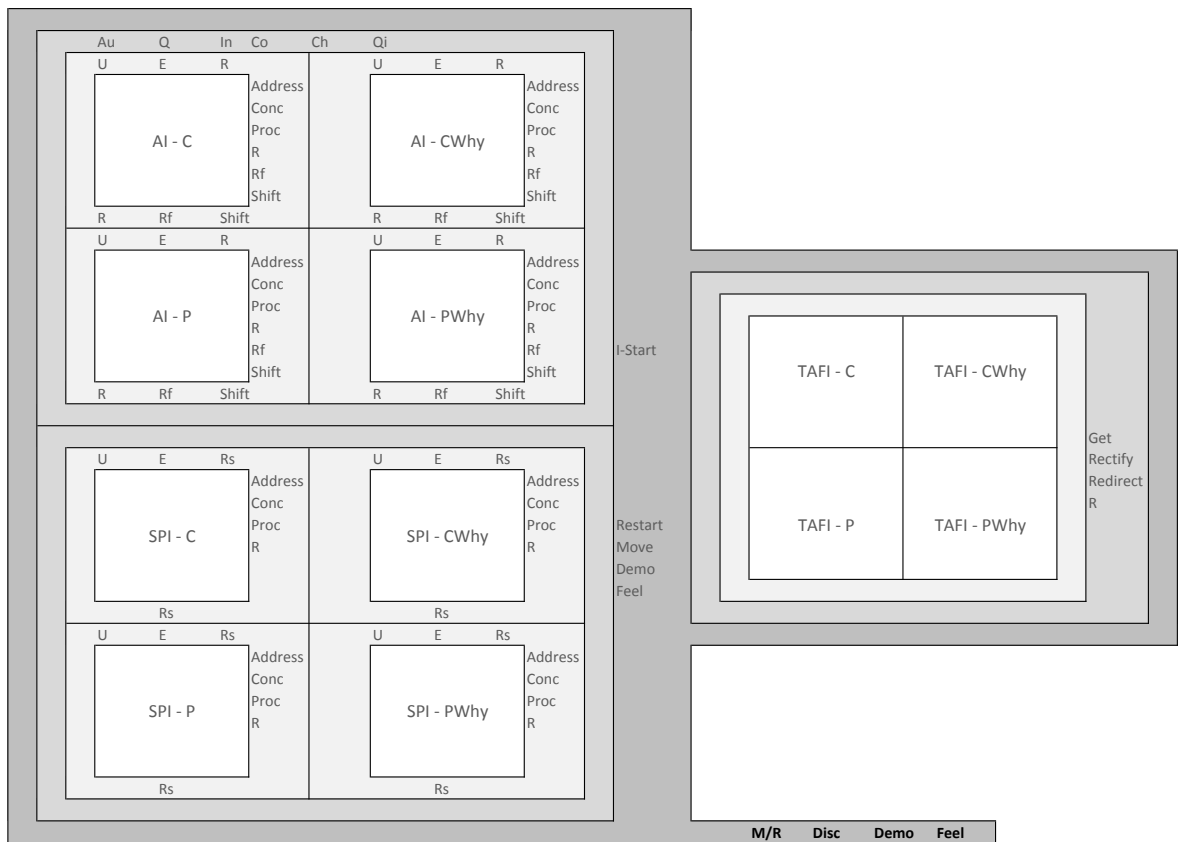


Figure 4.23: The list of other actions students may do after an interaction - M/R (Move or Restart), Disc, Demo, Feel - is added to the outermost layer in an extension along the bottom of the diagram.

Example: Other Possible Student Actions

I review the post interaction dialogue for the example to see which features emerge.

- Move - Students jump straight from correcting their Error of $W = 0$ during the interaction, to changing their procedural moves from setting W to 0 to identifying a formula for work and continuing constructing their solution. This is evidence that they are moving on in the problem on this new course where $W \neq 0$. I select this feature.
- Restart - Students can only either Move or Restart, not both. Students change course in declaring the formula for work. They have not shown behaviors of Restarting - erasing several terms, using language like "do over" - only of putting in a formula to continue where their used to be a zero. This (as well as the selection of Move previously) eliminates this features.
- Demonstrate (Demo)- In this case, there is not enough information given in the interaction for students to Demonstrate an understanding afterward. They are certainly influenced to move in a different direction, and do so. But there is nothing from the interaction they can really Demonstrate after their correction during the interaction. This can be eliminated.
- Discuss (Disc) - Students do map out the formula for work. However, this is not a Discussion begun during the interaction and carried on afterward. The interaction identifies their Error, and students change course afterward, making a correction. There is no genuine Discussion begun during the interaction and carried on afterward. This can be eliminated.
- Feel - Students are not emotive at all as they Move forward and give no evidence of Feelings. This can be eliminated.

Ultimately, the students Move forward with their solution construction but do not show any further possible features. I'll add Move to their diagram, seen in Figure 4.24. Note that Move is highlighted in yellow. Yellow will represent features that are not Issue specific, but belong to

the students alone. Note also that the diagram now contains more labels for the features not present but laid out in the previous two subsections.

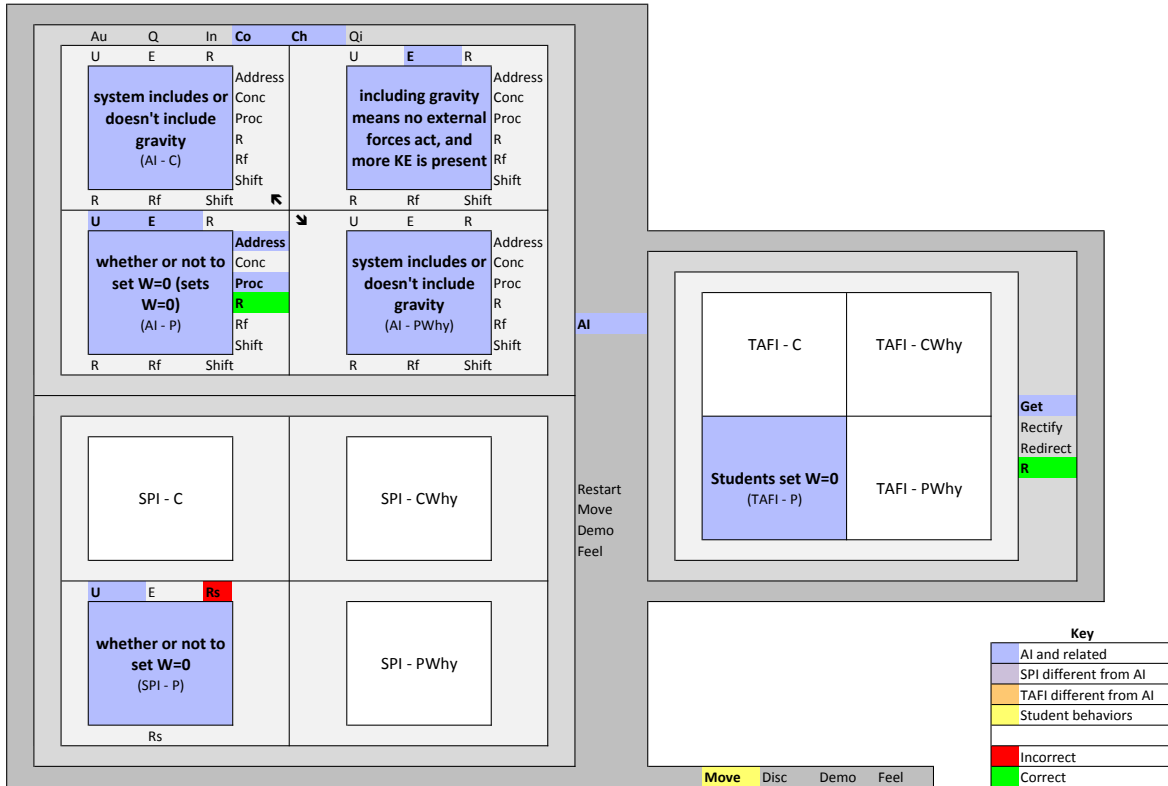


Figure 4.24: Other actions students may do during an interaction have been added to the outer layer, middle column of the example Issue diagram. Resolution features after the interaction have been added along the bottoms of each component of the AI and SPI in the second layer. None are highlighted as none were found to be present. The list of other actions students may do after an interaction is added to the outermost layer in an extension along the bottom of the diagram. The feature found to be present - Move - is highlighted in yellow. Yellow is added to the key and indicates student behaviors that are not Issue specific.

With this section, I have largely completed the analysis of the Issues and students' actions in relation to the Issues. I move on next to examining more behavioral aspects of the interaction.

4.1.5 Characteristics of the Interaction

This next section focuses on characterizing the interaction. Up to this point, I have identified how the presence of the interaction relates to what the students do before during and after the interaction, and I have introduced the TAFI as the contents the GTA focuses on. I have not analyzed any further characteristics of the interaction itself. However, having these characteristics allows me to describe the kind of interaction that enables the connections I've made. Thus, I now identify those characteristics. As I have already analyzed the contents the GTA focuses on, this will encompass both what the GTA does and what the GTA allows for or encourages the students to do. I'll do this by walking through the interaction in a temporal manner. I will look first at who decides the interaction should occur. I will then move to how the GTA diagnoses the students' Issue, deciding on a focal topic. Finally, I will explore how the GTA interacts with students while Addressing the chosen topic.

Who Begins

I begin this section with determining who begins the interaction. This can be the students or the GTA and is determined simply by who talks first at the beginning of the interaction (determined by data segmentation). That is, unless the students have raised their hand before the interaction. Then they automatically begin it.

Also of value is who initiates discussion on the Issue the students are having. If it is the first discussion of the interaction, this is the same person who begins the interaction. But some interactions run through more than one topic, so I also identify who begins these later topics. There tend to be natural breaks where one topic ends and another begins. Data segmentation can again be used to determine who selects a topic.

Who begins the interaction and topics helps determine whether the interaction and the pieces pertaining to specific Issues are requests for help - if begun by the students - or assertions of authority (and a possible Issue) - if begun by the GTA. Figure 4.25 shows these added in to the diagram.

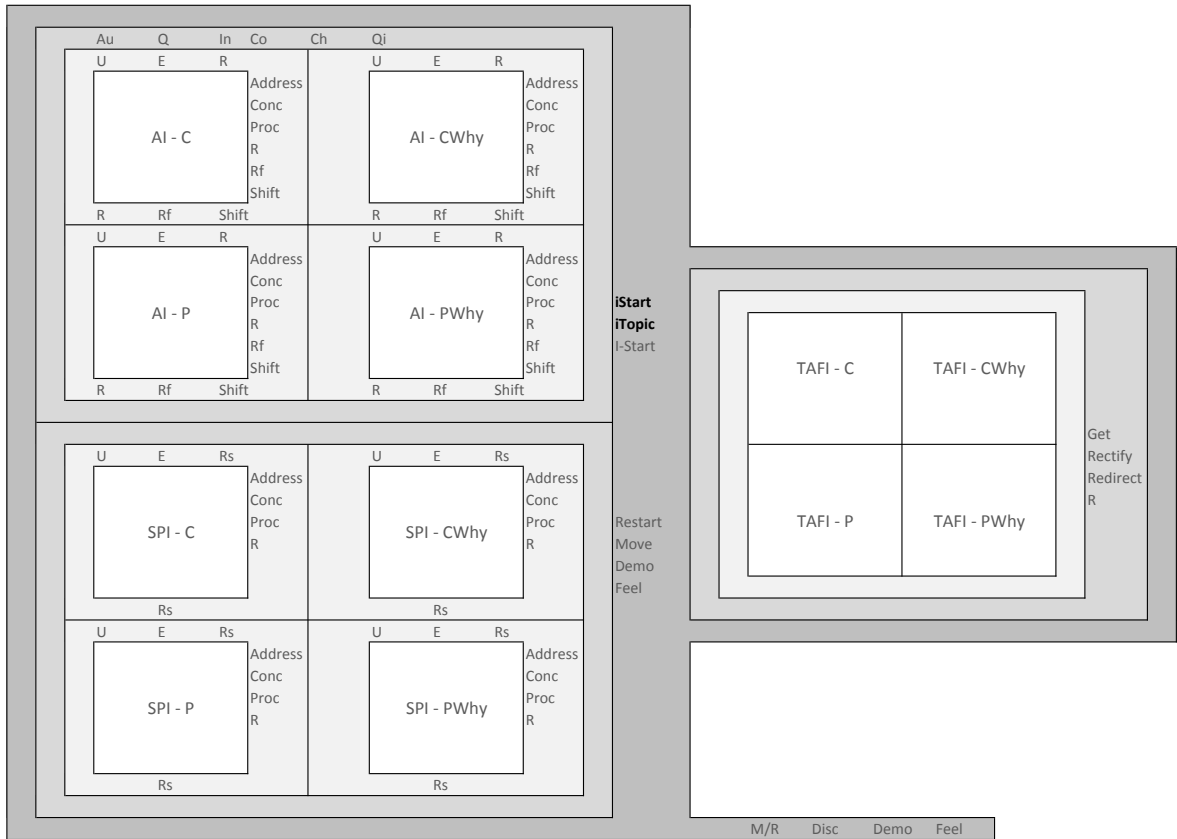


Figure 4.25: Two features indicating who began the interaction - iStart (GTA or Students) - and who began the Issue topic - iTopic (GTA or Students) - have been added to the middle column of the outermost layer.

Example: Who Begins

I analyze the example interaction a bit more and identify these features. I've reprinted the dialogue from that interaction again below for continuity.

- 62 **GTA:** Why is the work done zero?
- 63 **S2:** hmm?
- 64 **GTA:** Why is the work done zero?
- 65 **S2:** It's not?
- 66 **S1:** No. It's not zero.
- 67 **S3:** It won't be zero?

The students have not raised their hand before the interaction, and so the first statement of the interaction, and thus its beginning is by the GTA. Since there is only one topic and it is brought up immediately by the GTA, the GTA is the starter of the Issue topic as well. Figure 4.26 shows these features added into the example diagram. Note that the features are highlighted in pink, indicating they are GTA specific. Pink will represent features that are not Issue specific but belong to the GTA alone.

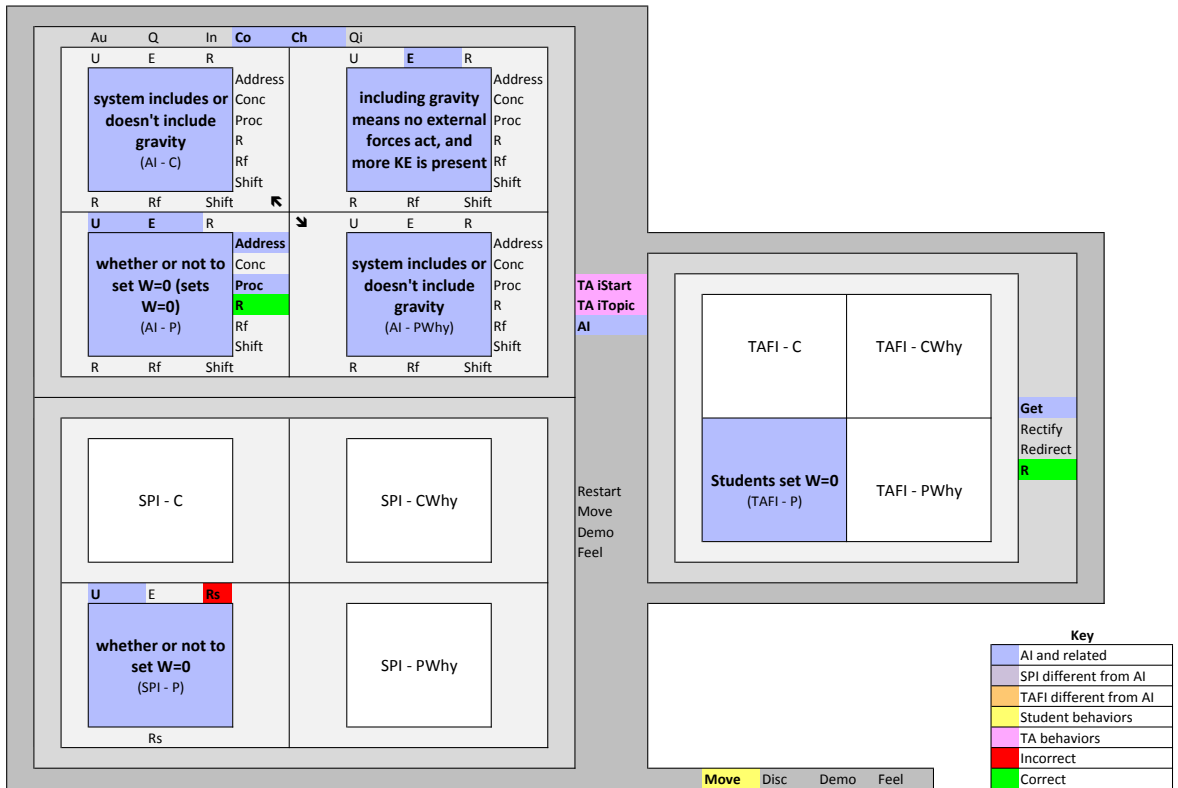


Figure 4.26: Two features indicating who began the interaction - TASTart - and who began the Issue topic - TATopic - have been added to the middle column of the outermost layer and highlighted pink helping indicate the GTA was responsible for these two things. Pink is added to the key and indicates GTA behaviors that are not Issue specific.

Diagnosis

In all interactions, the GTA must go through some type of diagnosis to figure how to focus his/her efforts. The diagnosis is the process through which the GTA decides on his/her focal topic. This identifies how the GTA connects what the students express and do before the interaction to what will be discussed during the interaction. The diagnosis typically happens at the beginning of an interaction. However, it may happen before an interaction begins if the GTA is listening to the students beforehand. It may also happen later in an interaction as one topic changes to another. I am less interested in when this occurs (marked by data segmentation), and instead I will focus on how it occurs. How it occurs indicates the level of student involvement encouraged or allowed by the GTA in the diagnosis process. The diagnosis is a way of identifying both how the GTA comes to focus on the TAFI as well as how the GTA encourages student participation in that process. The GTA can diagnose either:

- **Actively (Active)** - The GTA asks probing questions of students and repeats their ideas to try to gain understanding of their situation. The students give their input or in some cases work alongside the GTA to figure out their mistakes.
- **Passively through Listening (Listen)** - The GTA listens to students discuss the Issue but does not probe further. The GTA can do this either before the interaction begins or during the interaction (typically at the beginning of an interaction).
- **Passively through Work (Work)** - The GTA does not listen to students' discussion, but reviews students whiteboard and/or PC work. This typically happens after an interaction has started, but can occur before an interaction begins.
- **Abbreviated (Abbrev)** - The GTA and students engage in a very short and often incomplete dialogue before the GTA begins helping with the situation. This can occur a couple different ways:
 - The GTA listens to students ask a question and immediately begins helping.

- The GTA asks a question of the students, receives a brief answer, and then begins helping immediately. This is characterized particularly by its lack of probing for more information or space for ideas to be fully expressed, even though the GTA asks a question.

The addition of the diagnosis in the diagram is shown in Figure 4.27.

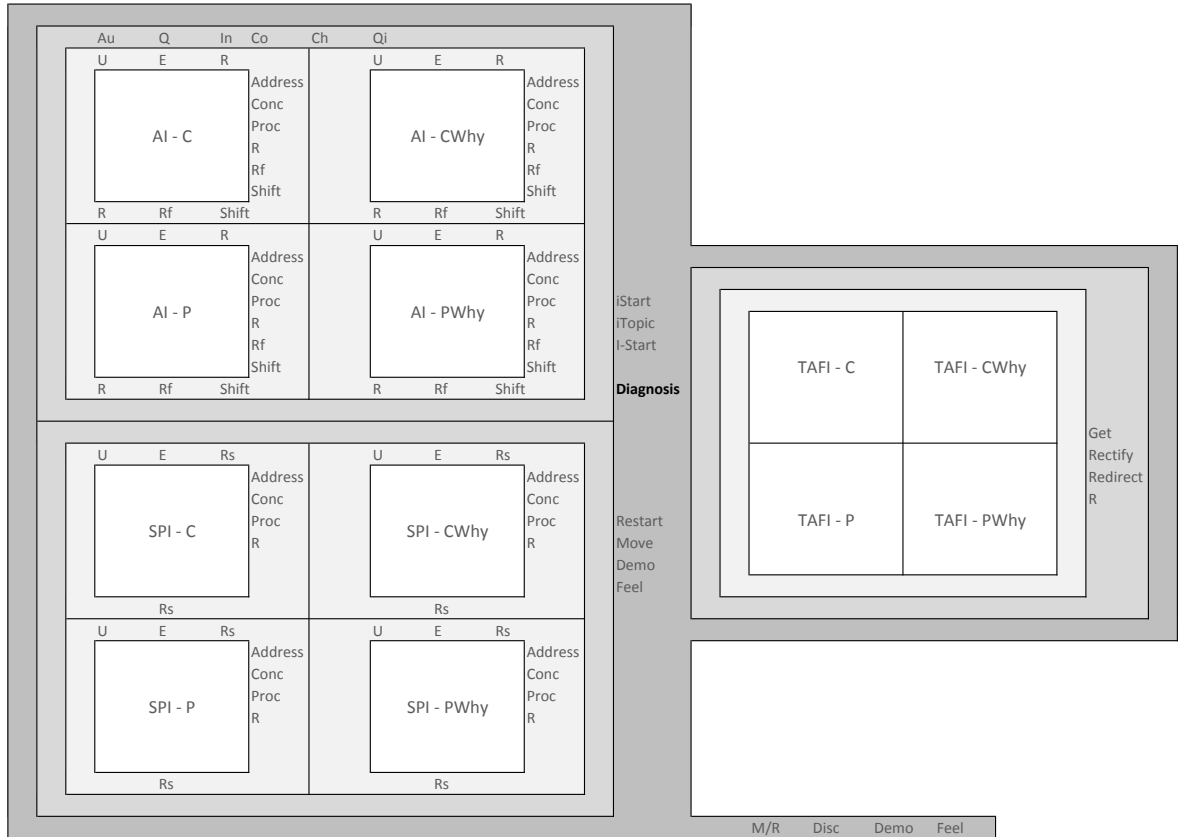


Figure 4.27: The Diagnosis feature - Active, Listen, Work, Abbrev - has been added to the middle column of the outermost layer.

These diagnoses are not mutually exclusive. More than one kind may occur as the GTA diagnoses the situation. In order to account for this, I rank them as they appear above (Active is first, Listening is second, etc.) based on the amount the GTA must focus on the students and

their work. When multiple kinds of diagnoses are used by the GTA, I select the highest one from the list.

- **Active** - The GTA helps pull the Issue out of the students through probing questions that encourage them to share ideas about the Issue. Or Students and the GTA work alongside each other to figure out mistakes.
- **Listen** - The GTA listens to students talk about the Issue in some way, allowing them to express at least one complete idea on their Issue. The GTA does not do anything to encourage them to continue talking or to stop them from continuing talking.
- **Work** - The GTA reviews the result of the students' Issue as it shows up in students' work.
- **Abbreviated** - The GTA and Students engage in one back and forth question and answer in which no more than one idea about the Issue is exchanged. The GTA stops the students from further questions and answers by beginning to help them.

Example: Diagnosis

Turning to the example, I add this bit of context to the transcript to identify the appropriate diagnosis: The GTA enters the frame ten seconds before the interaction begins. She watches S3 write out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard with no verbalizations from the students, and then she begins speaking.

This information, added to the first line of dialogue - "Why is the work done zero?" - leads me to think the GTA has used the time before beginning the interaction to diagnose, at least in part, what needs Addressing. Since she is not present for any verbalizations from the students, but clearly gains some information from their whiteboard work, I would call this diagnosis Work. It is possible that the GTA is asking a probing question and therefore trying to make a more active diagnosis. However, as I have described earlier, the response by the students and acceptance of that response by the GTA in the form of ending the interaction leads me to interpret the probing question as a correcting question. Thus, that question is not one of

diagnosis, but of Addressing the Issue. In identifying this, I interpret all diagnosis to have been done before the interaction begins, and I stick with the diagnosis feature of Work. Figure 4.28 shows this feature added into the example diagram.

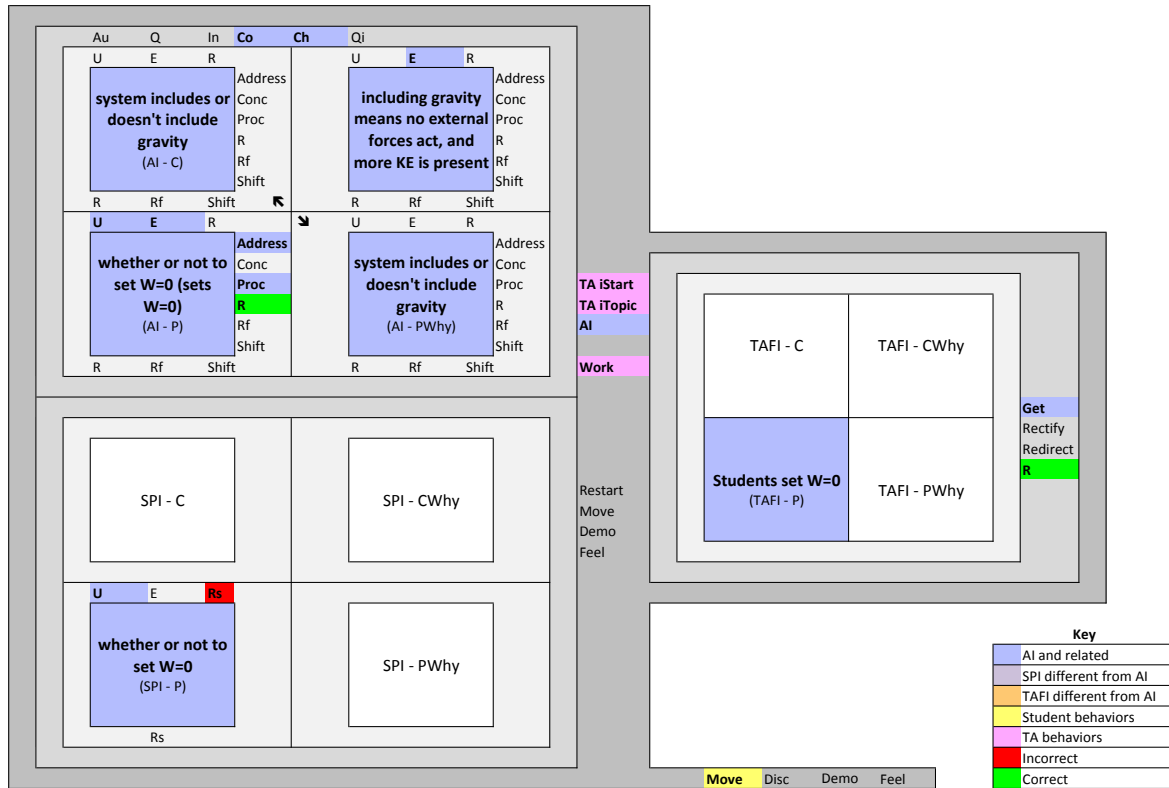


Figure 4.28: The Diagnosis feature - Work - has been added to the middle column of the outermost layer indicating a diagnosis done by reviewing students work. It is colored pink as it is a GTA behavior.

Once the GTA diagnoses the situation, I want to know how he/she progresses. In particular, I am interested in the style of conversation between the students and the GTA and in how much and what way the students participate. I will break the interaction down first by who directs it, and then examine how it is directed, addressing conversation styles and student participation.

Who Directs and How

The interaction is directed by one party having control over the flow and topics of the conversation. The interaction can be directed by either the students (any particular student or the group in general) or the GTA. Control can be most easily determined by noting which party, the students or the GTA, is participating in the conversation of the other party. This is detected in how topics of discussion are chosen, questions are asked and answered, and statements are delivered. Once I know who directs the conversation, I want to know a bit more about how it is directed by the controlling party.

The students direct the dialogue in one of three ways:

- **Question** - Students ask questions of the GTA, and the GTA does no more than answer those questions. The answers are fairly straightforward and flow directly from students' questions. The GTA is essentially serving the students' needs and no more. If the GTA begins to manipulate the conversation in attempting to answer questions, the students no longer direct it.
- **Sharing** - The students talk about what they think and share their own ideas and processes. The GTA participates in this conversation, but is largely at the whim of the students.
- **Disengaging** - The students will largely ignore the GTA and do their own thing. The GTA may continue talking here, but the students are not really following the GTA. This tends to occur when the students want confirmation on an idea and nothing more. They ignore any more that the GTA has to offer.

As the GTA directs the dialogue, he/she may encourage students' input. This is the aspect of direction I focus on for the GTA.

- **Seeks Student Input (Sinput)** - While the GTA directs the conversation, he/she encourages student input at some point during the dialogue. This encouragement can be

detected through the use of open or targeted questions by the GTA, actual directions by the GTA, or purposeful silences indicating the students can give input.

- Does Not Seek Student Input¹⁹ - The GTA does all the talking and does not encourage any student input. It is worthwhile to note here that the students might still give input, but that input is not in response to any purposeful GTA actions.

Figure 4.29 shows these features added to the diagram. Note again that these features and those prior I've talked about in this section are added to the central outer layer column. They are not specific to any particular Issue, but relate to the context of all three kinds of Issues.

¹⁹Indicated by a lack of highlighted Sinput

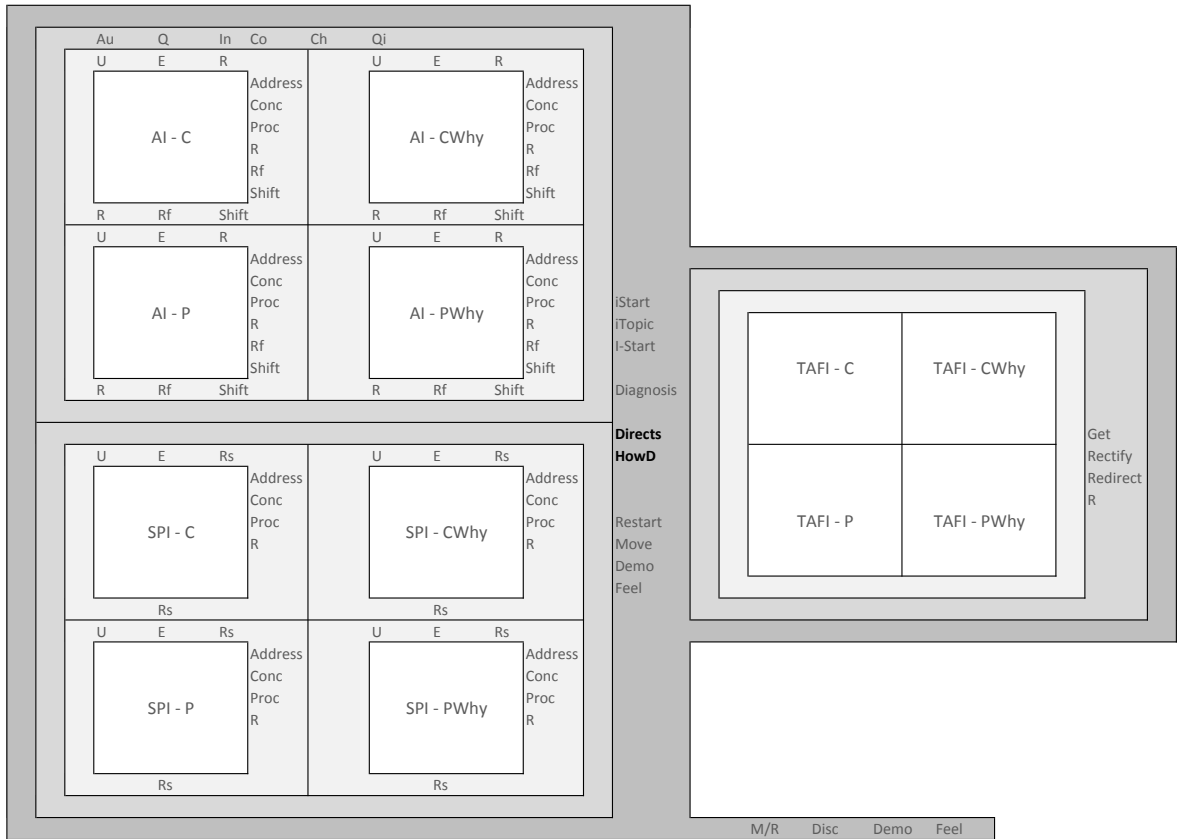


Figure 4.29: The features concerning who directs the interaction - Directs (GTA or Students) - and how they direct the interaction - HowD (Sinput or not for the GTA; Question, State, Disengage for the students) - is added to the middle column of the outermost layer.

Example: Who Directs and How

The example shows the GTA initiating dialog with her question and repeat of it in lines 62 and 64. The students immediately respond to her, coming into the interaction to meet her question and participating in her chosen topic. In this way, the GTA directs the interaction. Because she begins the interaction with a question for the students, even if that question is interpreted and intended as a correction, she is seeking students input to correct themselves or otherwise answer the question. She is not simply transmitting information to them. I'll add these features into the example diagram, making them pink to identify them with the GTA. Figure 4.30 shows this diagram with the features added.

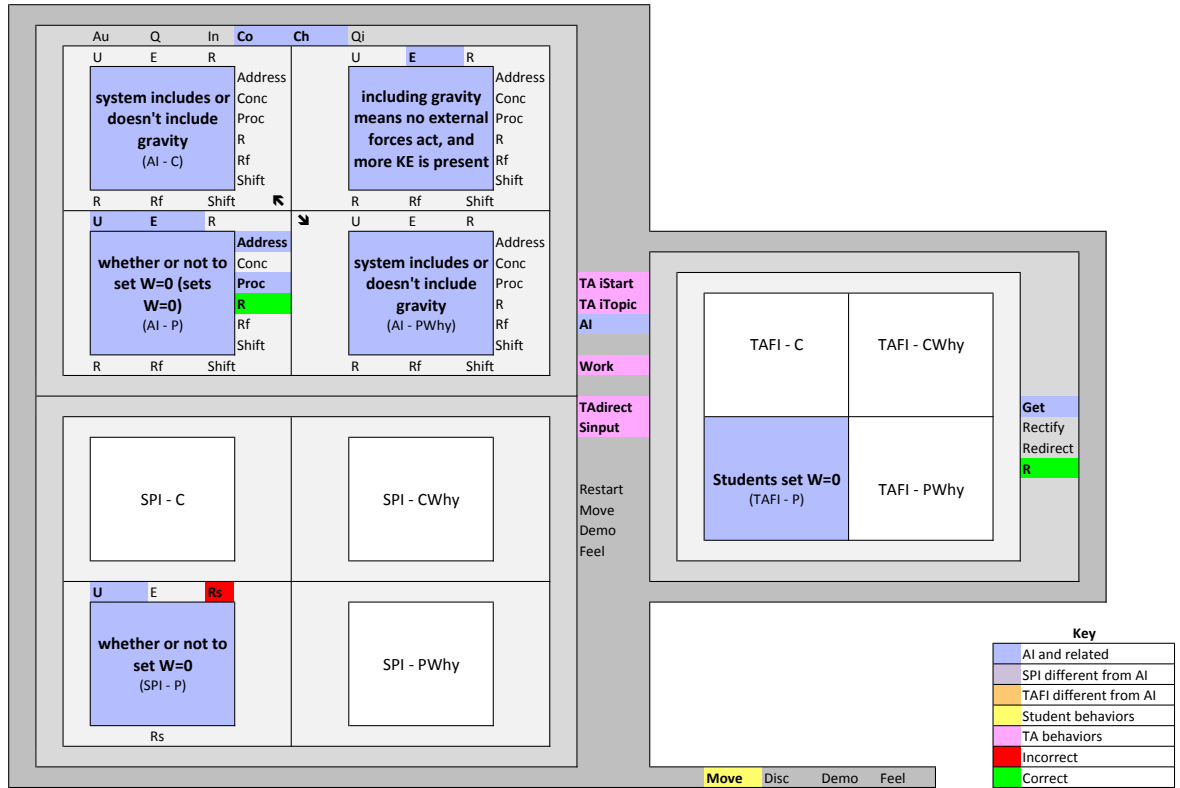


Figure 4.30: The features concerning who directs the interaction - TADirect - and how they direct the interaction - Sinput - is added to the middle column of the outermost layer. The features show the GTA directs the interaction and encourages student input. The features are highlighted pink, marking them as GTA behaviors.

Students Sharing Ideas

Regardless of whether or not GTAs encourage input, students can give input. This pertains to any particular student. Students can of course answer the more targeted questions the GTA asks them or simply engage in the process of Addressing the Issue without encouragement from the GTA. Sometimes students will also share their own ideas during a GTA-directed interaction. When these ideas come out they are authentic and belong only to the students. They are not simply corrections to mistakes or syntheses of the GTA's ideas. I will look to whether or not students share their ideas during GTA-directed interactions, and the generating factor for their sharing. Namely, I want to know if students are sharing ideas:

- of their **own accord (Own)**, spontaneously and without encouragement from the GTA or
- at the **prompting (Prompt)** of the GTA, either through questions, directions, or purposeful silences.

This feature gets added to the diagram in Figure 4.31. If students share ideas, this will be labeled with Own or Prompt and highlighted yellow or pink respectively. This is the last feature to emerge in the analysis. The framework is now complete. I will briefly analyze the example for this final feature.

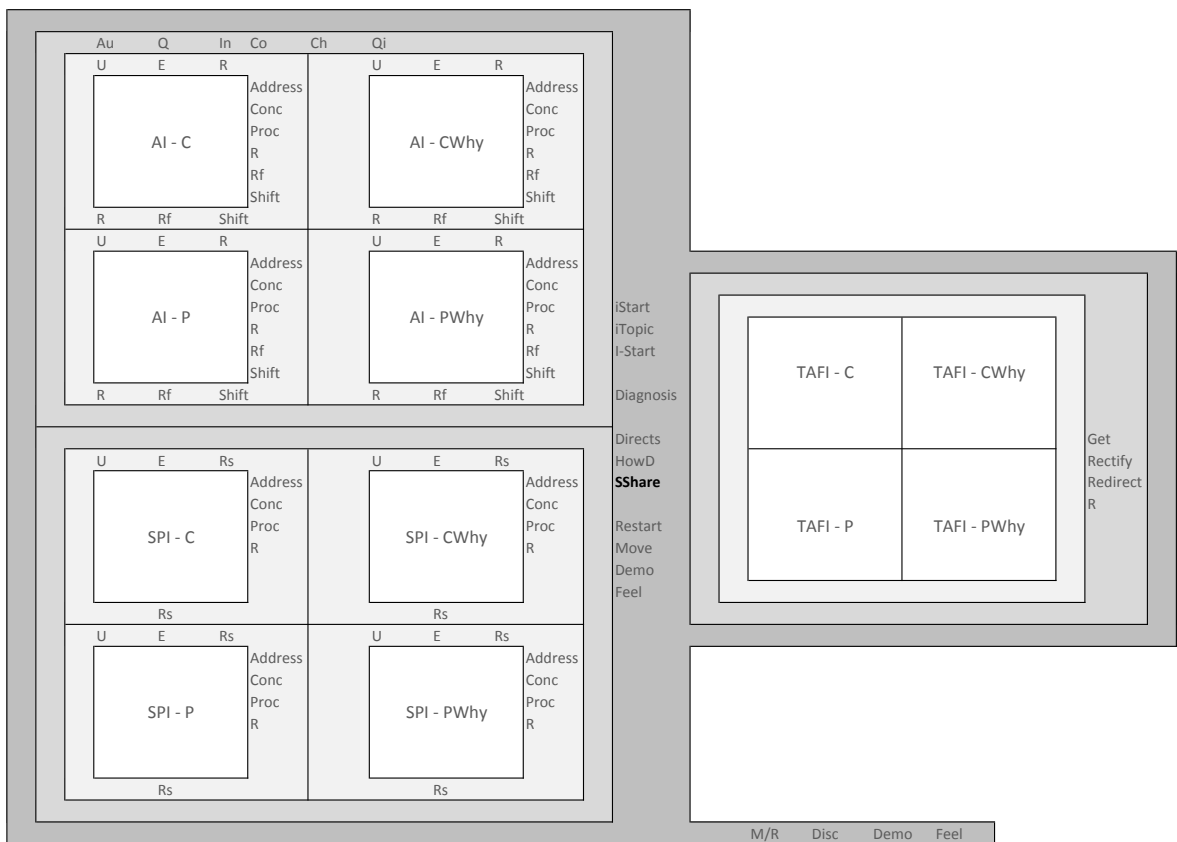


Figure 4.31: The feature indicating students sharing ideas - SShare - is added to the middle column of the outermost layer.

Example: Students Sharing Ideas

The brief interaction dialogue from the example shows that no students share ideas. S1 does share a correction to the group's mistake in line 66, but that is something synthesized at least in part from the interaction, not authentically his own. Thus, this remains unhighlighted in the diagram. The now complete example diagram can be seen in Figure 4.32.

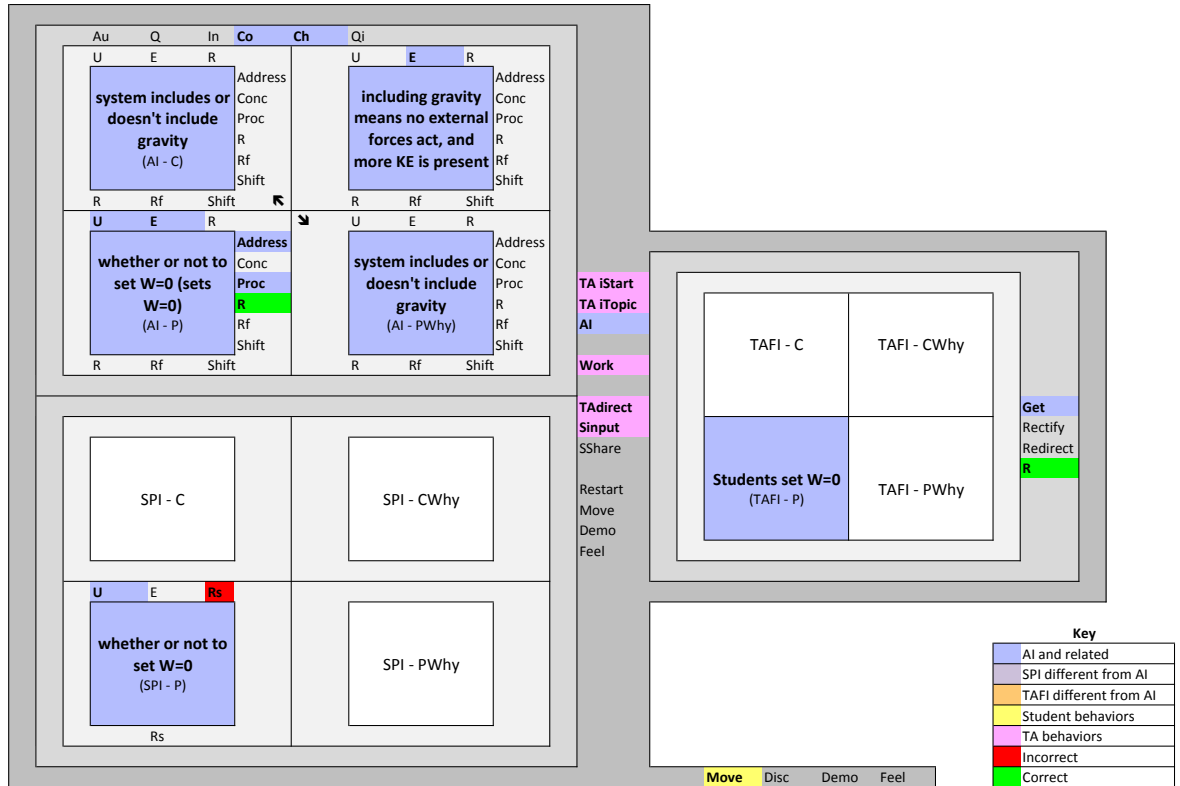


Figure 4.32: The full diagram for the example Issue shows all features with present features highlighted. The feature indicating students sharing ideas - SShare - is added to the middle column of the outermost layer.

Example: Cleaning Up the Diagram

Taking a look at the final framework in Figure 4.32 I see all the relevant features highlighted accordingly to tell the story of the example. However, there are redundancies, so I will clean up the diagram to retain only the truly relevant pieces are present.

The redundancies come out specifically when there are components of any two kinds of Issues - SPI and TAFI - that are the same as the AI. When these are the same, what happens during the interaction can be applied to all the components as the definitions of those common features are the same for all three kinds of Issues. Thus, any features present for more than one of the components become redundant as they are highlighted in all same components. Leaving all redundant highlighted features in place guides me to think, incorrectly, that multiple separate features are emerging. Removing those features allows me to see that those features are emerging once and can simply be applied to multiple components.²⁰ I am most concerned with what happens to the AI, and so I will leave those features alone. I will remove all redundant features from the SPI and TAFI as appropriate.

In the example, the redundant features are all those occurring during the interaction for both AI - P and SPI - P:

- Address
- Conc
- Proc
- R

and R for AI and TAFI. Figure 4.33 shows the simplified diagram with redundancies removed.²¹

²⁰This made it easier for me as a researcher to read the story in the diagram. It is not a hard rule of creating the diagram and should be molded to whatever works best for the researcher. If leaving redundant features in is more helpful to a researcher, do so.

²¹I only remove R for the TAFI because there is only one component and it is identical to the AI - P component. If there were more components, I would have to re-evaluate the appropriateness of eliminating R from the TAFI. I base this on whether further components are identical to the AI components, and whether all those AI components are also Resolved. Both would have to be true to eliminate the R in the TAFI.

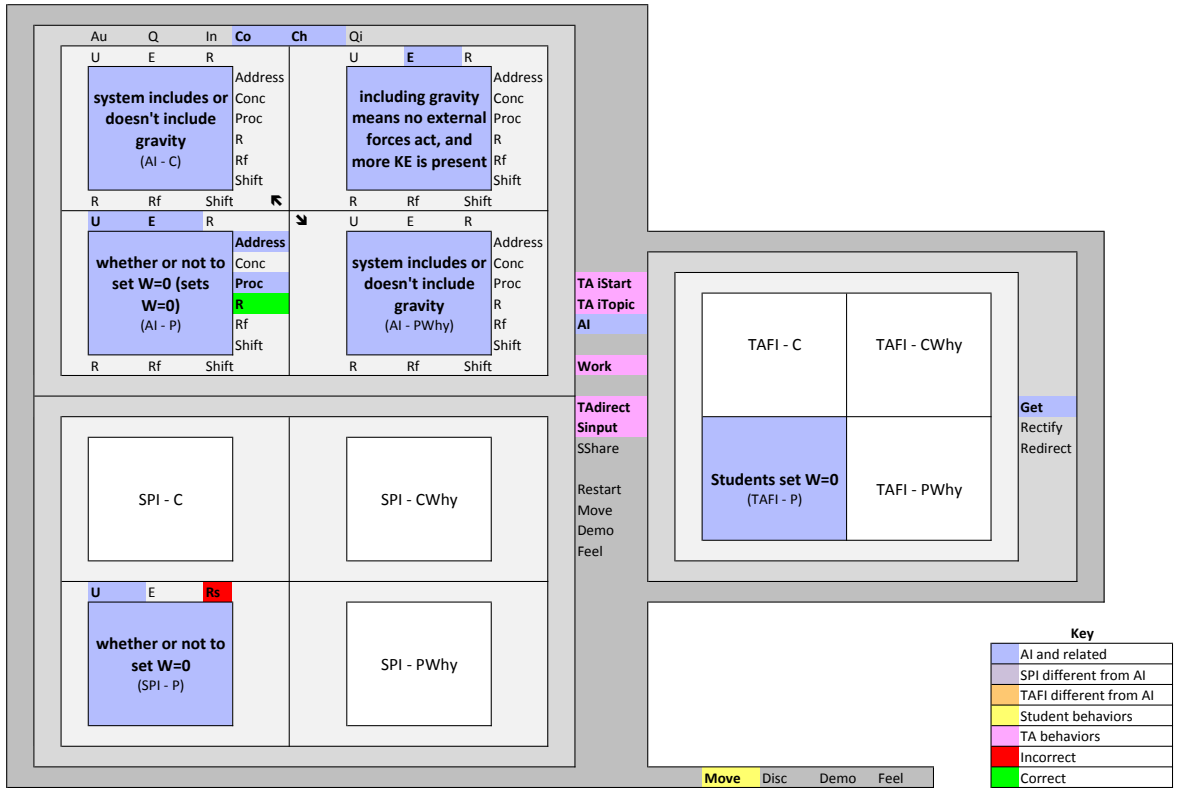


Figure 4.33: The completed diagram for the example Issue shows all features with case specific redundant features - SPI (Address, Conc, Proc, R) and TAFI (R) - removed. Features found present in the example are highlighted.

Completed Framework Map

Having now completed the creation of the framework and accompanying diagram, I'd like to comment more completely on the structure of the diagram. I've continuously noted the layering effect as I build out layers to apply features to components or to entire Issues. I have also discussed the use of color as I added it in and applied it to the example. I add on to these a note about the location of the features in the diagram. All features that emerge before an interaction begins are placed across the top of their respective layer. All features added during the interaction, including the entire TAFI, are placed along the side of their respective layers.

And all features added after the interaction are added along the bottom.²² In this way, I mark the three temporal stages - before, during, and after the interaction with the GTA - clockwise around the layers. Figure 4.34 shows an inner layer example of this, though the temporal locations apply to all layers of the diagram. In Chapter 5 I discuss results by temporal section. With this purposeful location of features added to the structure, I have three meaningful elements to help guide the interpretation of the diagram: layering, feature placement, and color.

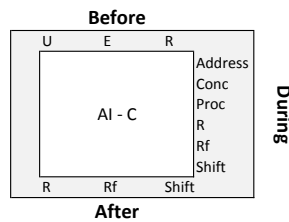


Figure 4.34: A sample of one component surrounded by its second layer. Time is indicated going clockwise around the diagram. All features along the top come out before the interaction (U, E, R). All features along the side come out during the interaction (Address, Conc, Proc, R, Rf, Shift). All features along the bottom come out after the interaction (R, Rf, Shift). All layers of the diagram are mapped in this way.

4.1.6 Issue Content Category

Examining the process of solving a physics problem, one can follow it through from interpreting the problem, to constructing and then executing a solution, to checking and evaluating the answer (Reif, 1994). Students may have Issues that include interactions with their GTA in any of these steps. It is then helpful to know where in the problem solving process the students' Issues arise. Different features of the framework may emerge within certain steps but not others. The steps themselves are separate from the framework, and simply act as content categories for the Issues. They create an easily observable way to categorize the various Issues and an

²²Features drawn in the extended bottom arm of the diagram are separated in such a way as to draw the readers eye to the true end of the diagram as the end of a reading page. This seemed clearer than leaving them in the outer layer right below the SPI. This is mentioned initially in the subsection "Other Possible Student Actions" after the interaction in Section 4.1.4.

interesting and useful perspective from which to review the results.

I typically examine the students' dialogue and actions before the interaction begins - the development of the AI and SPI - to determine the content category of the Issue. Issues typically fall into one of four content categories that can be found in two areas of problem solving:

- Construction - Students are in the process of interpreting the problem and crafting their solution.
 - Getting Started - Students are Uncertain how to begin interpreting a problem statement or constructing a solution
 - Solution Approach - Students have begun constructing their solution, but create Issues with specific structural pieces of that solution
- Execution - Students have constructed their solution and are working through the finer details of solving it.
 - Unit Conversions - Students create Issues around converting (or more often not converting) quantities into appropriate units.
 - Other - Students create Issues with the details of the calculations within their solutions. This includes Issues surrounding calculations, non physics formulas, organizing answers, etc.
- No Issue - Students do not create an Issue before an interaction. However the GTA brings up a topic as a possible current or future Issue during the interaction. Issues in this topic may belong in one of the above content categories, but are not placed there as they are not introduced by the students.

Once I have identified which category each data segment belongs to, I'll label the diagram with that category to provide further information when reporting results.

Example: Issue Content Category

To determine which category the example belongs in, I turn to the pre-interaction dialogue among the students. I reprint it below for continuity.

68 **S1:** Ah, work is zero, because you're- it's the surroundings... well...

69 **S2:** Well, then, how do you calculate the velocity if work is zero?

70 **S1:** 'cause your kinetic energy final equals fin-K, no, it needs...

71 **S2:** So...

72 **S1:** In this scenario, um, kinetic energy's going to be one half m v squared.

73 **S2:** And work,

74 **S1:** So it's going to be your final velocity minus your initial velocity.

75 **S3:** So final velocity equals initial velocity.

76 **S1:** Then your work- Your work is either going to be your gravity calculation then, or it's
77 going to be zero.

78 **S3:** It should be zero.

79 **S1:** Cause if you're choosing your surroundings to be, um, just the ball, you have to take
80 into effect gravity.

81 **S1:** But if you choose to make gravity, um, you include it in your system, then it's zero,
82 because there are no other forces acting on it.

83 **S2:** But it can't have zero in it, because zero makes everything zero.

84 **S1:** But, it doesn't necessarily, because if you chose to have the ball and gravity in your
85 calculation, your'e going to have more kinetic energy you have to calculate, so...

86 **S3:** (Writes out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard)

87 **S1:** one half m v squared final...

Students have written their energy principle with the appropriate needed terms before entering this dialogue. This puts them beyond a Getting Started Issue. They are attempting to decide what to put in for the various terms in their energy principle. At first glance, assigning zero to a term (lines 68, 78, and 86) might seem like an execution move. However, this is not done as part

of a calculation but as the proper assignment for the full work term. Reasoning using physics is applied to the Issue, and the term is dealt with by valuing it as zero. No real calculation or unit conversion has been considered yet. Thus, the content category of this Issue is Solution Approach.

Figure 4.35 and Figure 4.36 shows the final framework diagram and the example diagram side by side, complete with labels.

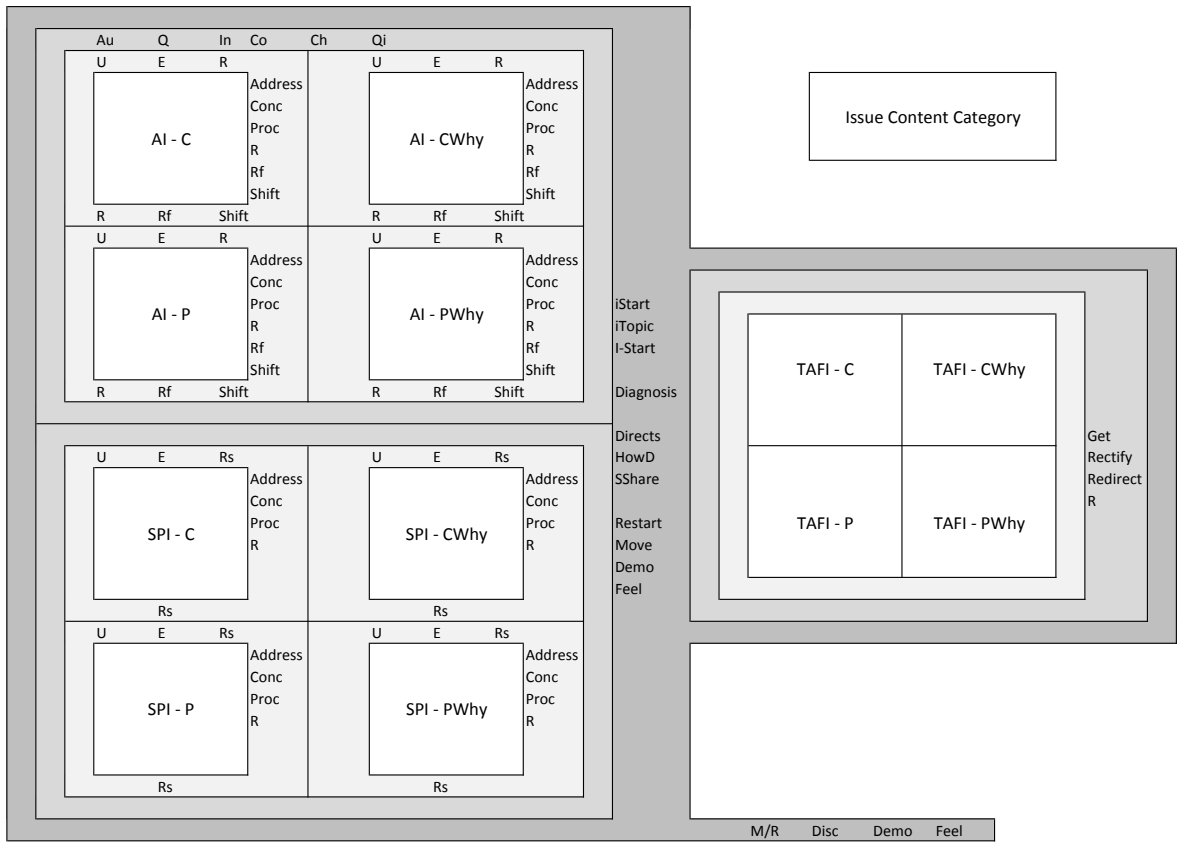


Figure 4.35: The complete diagram frame is shown including the label for its Issue content category in the upper right.

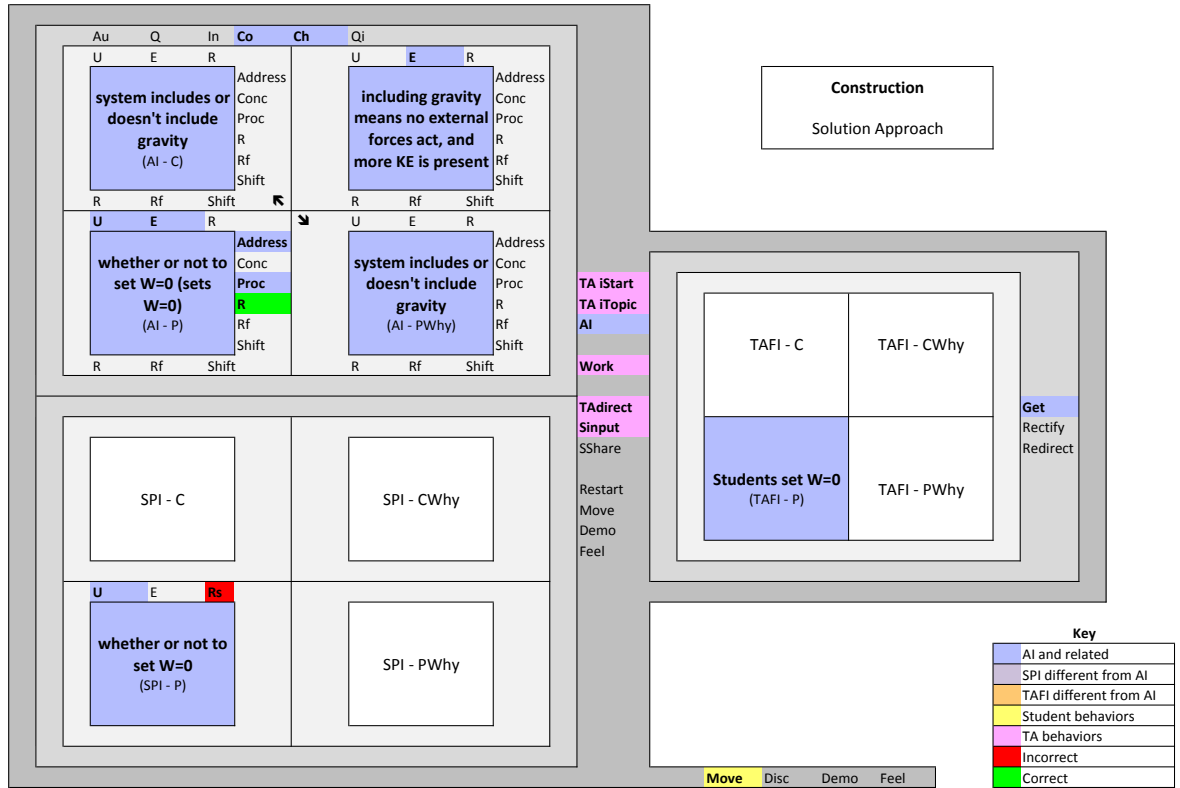


Figure 4.36: The complete diagram of the example Issue is shown including the label for its Issue content category - Construction: Solution Approach - in the upper right.

4.1.7 Influences on the Issues Framework

As mentioned in the introduction to this chapter, several previous studies influenced my analysis as I developed the Issues Framework. They colored the way I looked at the data as well as provided insight into the possible range of features that could emerge. I discuss these influences here and refer to the specific pieces of the framework the studies influenced as appropriate.

Physics Content: Procedure and Concepts

To understand how physics content was expressed by students in my study as they created Issues, I initially attempted to map their physics content process using conceptual proposition maps as described in Hogan et al. (2000). However, I quickly learned that the students' expres-

sions in my data were often only procedural or included very little conceptual discussion. The physics content was largely wrapped up in their procedure. Thus, I could not make maps of their conceptual reasoning as there was not enough of it expressed to do so. This influenced me to take a more macroscopic focus on students' expressions of content. The macroscopic focus was then influenced by Robinson (2000) and Krystyniak and Heikkinen (2007).

Robinson (2000) and Krystyniak and Heikkinen (2007) influenced my focus on the dual procedural and conceptual nature of students' Issues as well as the kind of talk used to address the Issues during the interaction. Robinson (2000) used an observation evaluation that included specific areas for rating GTAs's focus on "chemistry concepts rather than merely procedures," (Robinson, 2000, p. 159) as well as students "engaging in 'chemical conversation'" (Robinson, 2000, p. 159). Additionally, Krystyniak and Heikkinen (2007) categorized verbalizations along the varying procedural steps of an experimental lab and added the possibility for a conversation about chemical concepts to be present at any one of those steps. Robinson (2000) and Krystyniak and Heikkinen (2007) influenced me to focus on emergent concepts that macroscopically accounted for "Procedure" and "Concepts." This comes out in the division of the specific components of the Issues as well as in the division of the kinds of talk used to Address an Issue: Procedural and Conceptual. Krystyniak and Heikkinen (2007) also influenced me to not only describe the Issue and its Address in this dual nature but also to allow for the possibility of it in every case. This helped influence the structure of the framework in that I created the option for each component and kind of talk to be displayed in every case, rather than coding each one separately as Procedural, Conceptual, or Both and only displaying the selected code. Providing the option each time and displaying it visually allows for stark contrasts to be easily seen.

Interaction Characteristics

Before solidifying the specific emergent concepts of the interaction characteristics, I attempted to better understand the interaction by examining the details of the GTA-student dialogue. This analysis was influenced by several previous studies consisting of patterns of interaction dialogue

as well as ranges of GTA interaction behaviors (West et al., 2013; Kyle, Penick, & Shymansky, 1978; Sinclair & Coulthard, 1975; Ruiz-Primo & Furtak, 2007; Van Zee & Minstrell, 1997). These, as well as descriptions of GTA observation evaluations in a few of the GTA training studies (Etkina, 2000; Robinson, 2000), helped me analyze characteristics of the interaction on a spectrum from more teacher-centered to more student-centered. This perspective influenced the kinds of features that emerged in this portion of the framework.

Dialogue Patterns

After identifying the four components (P, PWhy, C, and CWhy) and the three kinds of Issues (AI, SPI, and TAFI), I examined the interaction dialogue for possible connections between dialogue patterns and the specific components of the Issues. I did not find any connections to specific components, and so I eventually turned to different methods of analysis. However, this analysis provided insight into the nature of the GTA-student interactions that later developed into framework features. Therefore, I review this part of my analysis process here.

I segmented the interactions into talking turns (with additional segments to break up a speakers independent topical changes) and analyzed the patterns of dialogue revealed in my initial sample of data. I compared these patterns to those found in the literature on teacher-student interactions (Sinclair & Coulthard, 1975; Ruiz-Primo & Furtak, 2007; Van Zee & Minstrell, 1997). I found multiple instances of what seemed to be²³ triadic dialogue (Initiate-Respond-Evaluate, IRE) (Sinclair & Coulthard, 1975) but only rare instances of the extended pattern of dialogue (Elicit-Student-Recognize-Use, ESRU) (Ruiz-Primo & Furtak, 2007) and reflective toss (Van Zee & Minstrell, 1997). Some dialogue seemed to better fit a student-teacher-student triad in which a student asked a question, the teacher answered it, and the student acknowledged the answer.²⁴ This identification became the base for a deeper analysis of how students directed some interactions. Additionally, while GTAs seemed²³ to use triadic dialogue to encour-

²³ I use the phrase “seemed to be” as I did not conduct rigorous analysis of the dialogue using these particular patterns. I was interested in what they might reveal and whether a particular pattern would emerge as more helpful than the others. Due to the variation in kinds of dialogue, I did not find that.

²⁴In some cases the student shared an idea, the teacher confirmed it, and the student moved on.

age students to participate in the interaction, they also gave longer explanations and directions in many interactions. Thus, the dialogue patterns I observed were varied and only partially reflected in the previous literature.

Examining my data by reviewing the dialogue patterns revealed behaviors in both the GTA and the students that eventually developed into concepts of Who Directs the interaction and How it is Directed. For example, the instances of triadic dialogue, explanations, and directions set the stage for the Sinput feature (encouragement of student input). This design also acknowledged the presence of interactions in which students control the flow of the interaction and allowed for a variety of kinds of control.

Observation Protocols: RIOT and SLIC

Reviewing my initial sample of data using the range of categories described in the Real-time Instructor Observation Tool (RIOT) protocol (West et al., 2013), I saw that the GTAs seemed to conduct interactions mostly within a very narrow range within that protocol. In my sample, GTAs were typically Listening, Explaining, or using Closed Dialogue.²⁵ Where attempts seemed to be made at Opening the dialogue, they were quickly shut down again. Thus, the RIOT protocol did not seem to be the best way to understand how the interaction was conducted. However, it did give me a spectrum of behaviors and descriptions in which I could better understand the behaviors I saw. The descriptions of Closed and Open Dialogue specifically helped me attend to GTAs' encouragement of student input. This allowed me to pull out the presence of three possible levels of encouragement of student input in my data: none (absence of Sinput), present but targeted or closed (presence of Sinput), and seeking students' ideas (Prompt).

I also tested Science Laboratory Interaction Categories (SLIC) on my data (Kyle et al., 1978). This protocol is recommended for experimental labs, but I wanted to see what it might reveal in my data. The range of behaviors described in SLIC generally fit the sample of data in

²⁵West et al. (2013) describe 15 GTA interaction behaviors in the RIOT protocol.

my study. However, to be true to what my data revealed, I would have to extend the categories to include a larger variety of kinds of questions asked²⁶ as well as modify the details of the category descriptions for behaviors seen in problem solving activities.

Yet, the category descriptions in SLIC provided ways to describe the GTAs' behavior in various interactions. For instance, I noticed that GTAs rarely asked Factual Recall Questions or Acknowledged students behavior in my initial sample of data, but they did offer explanations or direct students to do something (Transmits and Gives Directions). The fact that they were not asking students for a description of what they'd done (Factual Recall Questions) led me to ask how they learned about the Issues students created. From this question emerged the concept of diagnoses and segmenting the interaction portion of the data segment further into a diagnosis section and a post-diagnosis section (see Section 4.2). Analyzing my data for kinds of diagnoses, then, led me to understand the various ways GTAs learned about students' Issues. Additionally, the Listening and Observation categories from both SLIC and RIOT helped me understand some of the behaviors that differentiated the Listening diagnoses from Abbreviated diagnoses in the Issues Framework: primarily the observation of students talking to each other (Listening diagnosis) versus asking the GTA a question (Abbreviated diagnosis). Comparing the Observation category to the Reads/Writes category in SLIC provided a basis for identifying Work and Listening as separate diagnoses types as well.

This section reveals the influence previous research had on the development of the framework. I do not extend or use any particular observation protocol or dialogue pattern. But testing each one with my data illuminated different characteristics of the interaction that became features of the Issues Framework.

4.1.8 Complex Example

In the preceding sections, I developed the framework slowly and built an example alongside it as I did so. The example was fairly simple, in part due to the brevity and clarity of the interaction.

²⁶I would have had to widen the range of questions asked to include clarifying and targeted questions and possibly others.

I will now build the framework for one additional, more complex example to solidify the process and highlight a few different features.

This example is taken from a group of students constructing a solution to the final kinetic energy of two daughter nuclei after fission. I print the full problem below in Figure 4.39 for clarity. The students have begun constructing their solution and are trying to determine how to find their kinetic energy. Their initial state is the single particle before fission (c in the problem diagram), and their final state is the two particles, traveling very far apart from each other (b in the problem diagram). I'll print the entire transcript for this data segment below and refer back to it as I analyze the Issue. Dashed lines refer to breaks in time in which other pieces of the problem were discussed that do not relate to the data segment. The Issue creator's name, S2 in this case, will be colored red for clarity.

88 **S2:** Or would it be like, because they're so far apart, the potential would basically be zero?

89 **S2:** So you when you solve for the potential you find kinetic.

90 _____

91 **S2:** So if we do - maybe we could just use the, that equation to find... K?

92 _____

93 **S2:** ...divided by (writing out on the whiteboard as can be seen in Figure 4.37)

94 **S2:** whatever the distance is (searching the problem statement for a distance)

95 _____

96 **S2:** So it's when they're very far apart.

97 **S3:** See, I don't understand how to do very far apart.

98 **S3:** Like, what does that even mean?

99 **S2:** Yeah. 'Cause for this, we need, like, the exact distance.

100 **S3:** Yeah.

101 _____

102 **S2:** Er no, U is going to be zero, so we (undetectable) - okay cool.

103 **S3:** Yeah. U's zero.

104 **S3:** Kinetic then,
105 **S2:** is gonna basically just be the opposite of U.
106 **S3:** Y-Yeah. Yeah. Right?
107 **S2:** I think so, 'cause KE plus U equals the energy plus the rest energy.
108 **S3:** Yeah. That makes sense.
109 **S2:** Sooo... (writes out solution on whiteboard, mumbling. See Figure 4.38)
110 **S2:** And then... I guess we still need the distance, don't we?
111 —————- (**Interaction Begins**)
112 **S3:** All right. I what are we supposed to use for like distance apart?
113 **S2:** Yeah. We're -
114 **S3:** I don't know.
115 **GTA:** Okay. So first thing - You're looking at state b and c, right?
116 **S2:** Yeah.
117 **S1:** Yeah.
118 **S3:** mmhmm.
119 **GTA:** First look for what are the energies in state c.
120 **S2:** Yeah. We found that.
121 **S3:** Yeah.
122 **GTA:** Does it have potential energy?
123 **S2:** Uh. Yes.
124 **GTA:** y - Why?
125 **S2:** Because it doesn't have any kinetic.
126 **GTA:** There's just one object.
127 **S2:** Okay.
128 **S3:** S- It doesn't.
129 **GTA:** Potential energy means interaction between two objects.
130 **S3:** Okay.

131 **S2:** Oookay. So-

132 **GTA:** So no potential energy.

133 **S3:** mmhmm

134 **S2:** No potential. Okay.

135 **GTA:** Kinetic energy?

136 **S2:** No.

137 **S3:** No.

138 **GTA:** So what then does it have?

139 **S2:** Rest.

140 **S3:** Rest?

141 **GTA:** Yes.

142 **S2:** Okay.

143 **GTA:** And what about state b?

144 **S2:** Uh. b has all three.

145 **GTA:** No.

146 **S2:** Er. It doesn't have rest energy?

147 **GTA:** It has rest energy.

148 **S2:** Okay.

149 **GTA:** It's moving, so it has kinetic energy.

150 **S3:** But the potential doesn't change.

151 **GTA:** It says very large separation.

152 **S2:** So the potential would be zero.

153 **GTA:** Yes.

154 **S3:** Yeah.

155 **GTA:** When you are very far away, you can not interact.

156 **S2:** Okay.

157 **GTA:** So now you need to equate the rest energy of state c

158 **S2:** Yeah.

159 **GTA:** to kinetic energy plus rest energy of state b.

160 —————- (**Interaction Ends**)

161 **S2:** That still doesn't really help us with this, though.

162 **S1:** Kinetic. We have to have kinetic too.

163 **S2:** Yeah.

164 **S3:** Uh. Yeah.

165 **S2:** (laughs)

166 **S3:** Sooo, what is that distance, very far apart?

167 **S2:** Yeah. 'Cause it's, like-

168 **S3:** I- I don't know how to do that.

169 **S2:** So there's no potential 'cause they're far apart.

170 **S3:** Yeah.

171 **S2:** So k- kinetic would be-

172 **S1:** So that just- What if they're, like, so far, they're, like, far apart that it, like...that would

173 be um... zero?

174 **S2:** You mean the kinetic? er-

175 **S1:** It was....

176 **S2:** So if the potential is at zero, then the kinetic is going to be at its maximum.

177 **S3:** Yeah.

178 **S2:** So what would be the maximum?

179 **S3:** But what it?

180 **S2:**How could we find that?

181 —————

182 **S3:** Isn't this potential, formula for this?

183 **S2:** Yeah.

184 **S3:** I think this was the formula for...

185 **S2:** What?

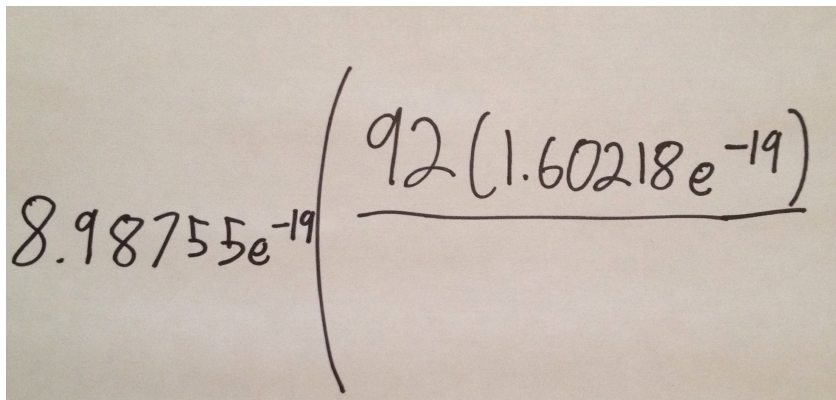
186 **S3:** I don't know.

187 **S2:** This is like, this is- this is the formula for potential,

188 **S2:** but I was thinking, like, if they're so far apart that potential zero, then kinetic is just
189 going to be the opposite of potential.

190 **S2:** So we can use, like, the same approach.

191 **S2:** This might be wrong 'cause I don't- we don't know what the distance is. There must
192 be some other equation we can use.



The image shows a student's handwritten work on a whiteboard. The equation is written as $8.98755e^{-19} \left(\frac{92(1.60218e^{-19})}{\text{blank}} \right)$. The numbers are written in black ink on a light-colored background.

Figure 4.37: Student whiteboard work shows an attempt at solving for U with $k(92e)/(blank)$ filled in with numbers. It reads $8.98755e^9(92(1.60218e^{-19})/)$. Students lack a value for distance. This writing is a re-creation by the author for clarity.

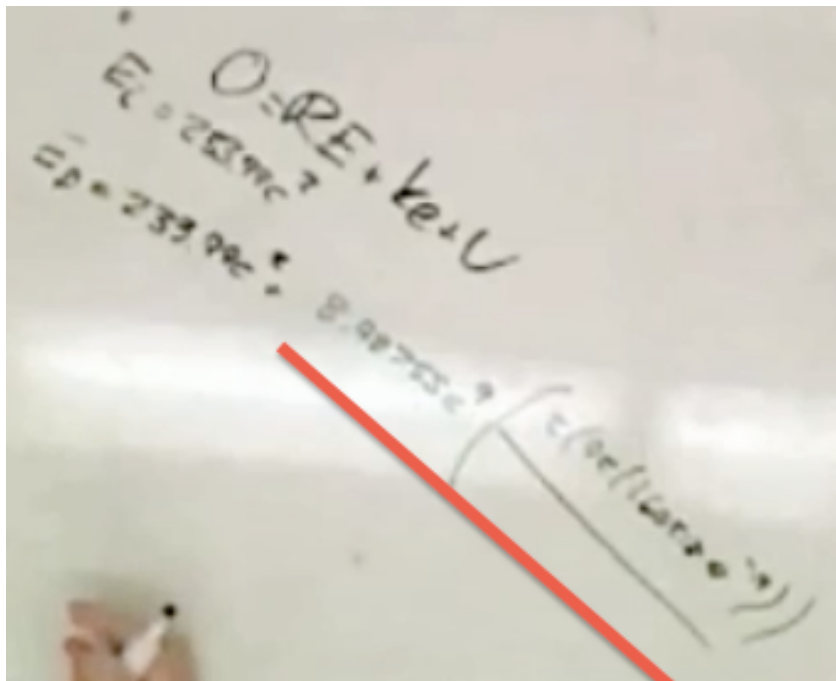


Figure 4.38: Student whiteboard work shows a more developed strategy with $E_i = RE$ and $E_f = RE + U$. The formula for U is substituted in for K . Rest energy is dealt with in a different Issue. Line 1: $E_i = 233.99c^2$ and Line 2: $E_f = 233.99c^2 + 8.98755e^9(2(92(1.60218e^{-19})))$

Figure 4.39: Fission Problem Statement includes the problem story, the story diagram (the correct order of events is c, a, b), and the first four questions asked of the students. Focus is on the last of these questions, but may take dialog and interactions concerning the first three questions as they appropriately pertain to the last question.

Fission Problem

For some isotopes of some very heavy nuclei, including nuclei of thorium, uranium, and plutonium, the nucleus will fission (split apart) when it absorbs a slow-moving neutron.

For example, uranium-233, with 92 protons and 141 neutrons, can fission when it absorbs a neutron and becomes uranium-234. The two fission fragments, called "daughter" nuclei, can be almost any two nuclei whose charges Q_1 and Q_2 add up to $92e$ (where e is the charge on a proton), and whose nucleons add up to 236 protons and neutrons (U-234, formed from U-233 plus a neutron).

One of the possible fission modes involves nearly equal fragments, palladium nuclei (Pd-117) each with electric charge $Q_1 = Q_2 = 46e$. The rest masses of the two daughter nuclei add up to less than the rest mass of the original parent nucleus. (In addition to the two main fission fragments there are typically one or more free neutrons in the final state; in your analysis make the simplifying assumption that there are no free neutrons, just two daughter nuclei.)

Objects involved in the reaction:

Nucleus	# of protons	# of neutrons	Charge	Rest Mass (atomic mass units)
U-234	92	142	+92e	233.99
Pd-117	46	71	+46e	118.393

Although in most problems you solve in this course it is adequate to use values of constants rounded to 2 or 3 significant figures, **in this problem you must keep 6 significant figures throughout your calculation.** Problems involving mass changes require many significant figures because the changes in mass are small compared to the total mass. **In this problem you must use the following values of constants, accurate to 6 significant figures:**

<u>Constant</u>	<u>Value to 6 significant figures</u>
c (speed of light).....	2.99792e+08 m/s
e (charge of a proton).....	1.60218e-19 coulomb
atomic mass unit.....	1.66054e-27 kg
$\frac{1}{4\pi\epsilon_0}$	8.98755e+09 N·m ² /C ²

Fission Problem (continued)

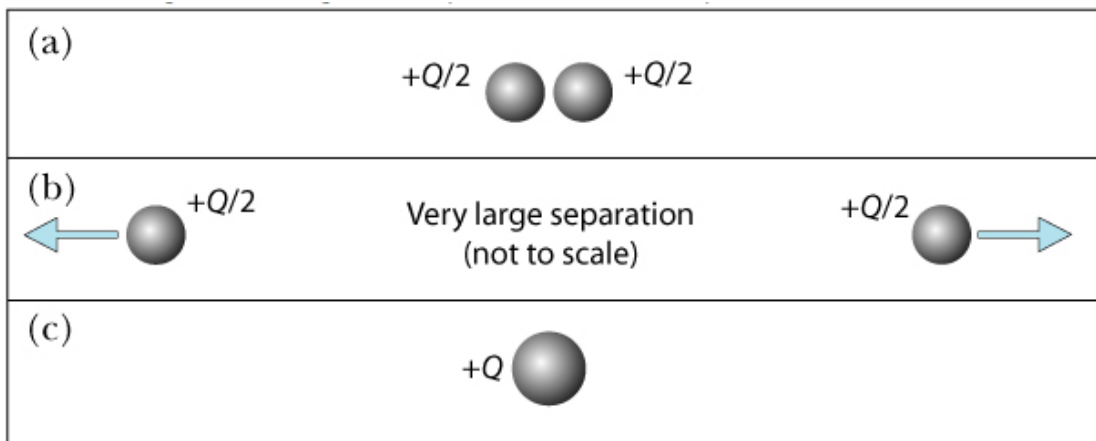
There are three states you should consider in your analysis:

- (1) The initial state of the U-234 nucleus, before it fissions.
- (2) The state just after fission, when the two palladium nuclei are close together, and momentarily at rest.
- (3) The state when the palladium nuclei are very far away from each other, traveling at high speed.

A: The final speed of the fission products

Your first task is to determine the final speed of each of the daughter nuclei in state (3), when they are far from each other.

Here is a diagram showing three important states in the process:



Fission Problem (continued)

Which diagram depicts the state of the original uranium nucleus? We'll take this state to be the initial state.

- a
- b
- c

Which diagram depicts the state when the two daughter nuclei have reached their final speeds? We'll take this state to be the final state.

- c
- b
- a

Compare the initial and final states of the system. Which quantities have changed?

- potential energy
- kinetic energy
- rest energy

What will be the total kinetic energy of the two daughter nuclei when they are very far apart?

$$K_1 + K_2 = \boxed{} \text{ joules}$$

Actual Issue Contents (AI)

I'll start by identifying the AI and SPI. Right away, I see S2 wrestling with how to connect the physical situation to their mathematical counterparts. He identifies correctly that the particles are far apart, and the potential at a great distance is zero (line 88). He then continues with the incorrect reasoning (incorrect as it is inappropriate for this problem) that solving for the potential, then, will give the value of kinetic energy, suggesting that all the potential goes to kinetic at large distances (line 89). After that he begins working with the idea that potential and kinetic energies are interchangeable, and so begins writing out the (filled in) equation for potential energy (lines 104 - 107). His whiteboard work thus far can be seen in Figure 4.37.

In the first few lines, I see the development of a multi-component AI. S2 uses information in the problem of the particles being far apart (CWhy) to reason about potential energy at great distances in line 88 (PWhy). He then uses that to justify solving for potential energy to get a value for kinetic energy (line 89) (P). This line of thinking, if it continues progressing as such, will be the contents of the CWhy, PWhy and P components of the Issue respectively. The reasoning behind PWhy is conceptual reasoning (U at great distances is zero), and so would also get placed in the C component, making PWhy and C the same.

Of course, I've developed all of this within the first few lines of dialogue before the interaction. I must look to see how much the Issue shifts around to make sure I am in fact capturing it as completely as I can. Looking further along, I see S2 run into the problem of needing to put a number in for the distance between nuclei in order to calculate the potential energy (lines 94 - 100). This is not an Issue unto itself, but rather a secondary problem arising from the initial Issue of using the potential energy. It will not alter the AI. Further along in the dialogue I see S2 returning to repeating the Issue in slightly different language. He identifies that U will be zero and thus kinetic will be its opposite (line 102 - 105). This adds a bit of new information. S2 had not specified that kinetic energy would in fact be the opposite of potential, though it is suggested above that kinetic goes to potential. This piece of information adds to the C/PWhy component as it gives a reason for solving for U to get kinetic.

He further justifies this idea by identifying “KE plus U” as “the energy” that they add to the the rest energy in line 107. While it seems a bit confusing the way he says it in line 107, this idea is clarified by what he writes out on the whiteboard later in line 109, seen in Figure 4.38. All of this reasoning is in keeping with what I originally deemed to be the AI most generally, but with an adjustment for added information. None of S2’s reasoning or moves change, though as he moves forward with the idea, his work does advance from just writing out the formula for U to putting the formula in for the kinetic energy term in E_{final} .

Before finalizing this as the AI, I quickly review the rest of the dialogue for any further clues to clarify the Issue. I find it especially significant here as the student’s ideas are only somewhat clear in their present form and seem to require more interpretation on my part to identify. Looking through the interaction, I see the conversation focusing more on the specific terms that belong in the solution than on the contents of the AI. However, I also see S2 answering the GTA’s questions in line with his thinking on potential and kinetic energy in lines 122 - 125. Though these lines reference the initial state of the particle and not the final state the students are currently concerned with, S2’s reasoning provides further evidence that he sees kinetic and potential as inversely proportional (at least at their limits).

I am also somewhat confused by S2’s statement that the final state has all three energies (line 144). From the dialogue before the interaction, I know S2 identifies rest and kinetic energy as present. Then he substitutes potential to solve for kinetic. It is not apparent where this new identification of the presence of all three energies comes from. However, it is also not as relevant to the Actual Issue contents, as the Actual Issue contents are not really concerned with which energies are and are not present but with how kinetic energy should be found. That would be data for a different Issue entirely. Thus, I will let this piece of dialogue go and not attempt to incorporate it here.

After the interaction, a few lines stand out providing further evidence of the Issue contents and clarifying it a bit. In line 169, S2 says that there is no potential since the particles are far apart. This further solidifies the idea that U is zero at great distances but does not offer

further clarification. S1 then contributes the idea that their U term should be zero if they're far apart (line 172). S2's following question, "You mean the kinetic?" in line 174 seems to further clarify that S2 is in fact just using the formula for U to find kinetic energy. The term they are focused on is the kinetic energy term, and U is the formula that will solve for it. S2 adds further clarification in line 176 by explaining that kinetic energy is at a maximum when potential is zero. This greatly clarifies the C component of the Issue as it provides the specific reasoning for why U is opposite of K.²⁷ S2 then continues questioning how to find the maximum (line 178) and finally fully repeats his initial idea again in lines 187 - 190. This is exactly what he developed before the interaction, and so does not clarify it much, but it does solidify the content of his idea.

Reviewing the dialogue from during and after the interaction with the GTA was rather intense but did offer more helpful information. I come away from this review with a bit more clarification on S2's idea and greater confidence in the initial assignment of Issue contents. I note here that it is rare for further dialogue, especially after the interaction, to relate so specifically to the contents of the Issue as it develops before the interaction. The attention needed to review this dialogue is something that makes this particular example much more complex.

Before moving on, I will review the finalized AI:

- C - U is zero, so K is maximized
- CWhy - The particles are very far apart (reasons why U is zero)
- P - Solving for U will give K
- PWhy - U is zero, so K is maximized

Finally, I'll solidify the Issue creator. In this example, S2 is the main generator of all Issue components. While again, he does not act without feedback from S3, he is the dominant member in driving the creation of the Issue. S3 serves as a sounding board and does not really generate her own ideas, but feeds off of S2's ideas, either agreeing or questioning. S1 does not talk or do

²⁷While I cannot say for sure, it seems S2 is using the idea that all potential energy turns into kinetic energy as is true between states a and b of this problem, but not between states c and b (as given by the problem statement and diagram in Figure 4.39).

much at all until after the interaction, and so can not be an Issue creator. S2 is the Issue creator.

SPerceived Issue Contents (SPI)

Before I show the diagram for these components, I'll also determine the SPI. I recognize that S2 is not fully confident in his reasoning and idea. He first presents it as a question, and then decides to follow it (lines 88 - 94). Later on, S3 seems Uncertain of his idea, even as she affirms it (line 106). S2 continues with this idea. It seems they might view the development of this idea as an Issue in itself with their Uncertainty towards it. However, the students run into a secondary problem as I mentioned briefly above; they don't have a value for their distance (lines 94 - 100). They only have the words "very far apart." They even admit not really knowing what is meant by that (though S2 seems to understand that it means their U is zero). It is this problem that they come back to twice as they reason through their Issue. While doing so, they do not come around to identifying that their original idea might be a problem, but simply that they need a number for distance. This, then, is the content they focus more on as an Issue. This is solidified further as S3 asks the GTA initially about the value for distance, not about S1's approach (line 112). This then, is their SPI. There are two components here:

1. P - students can't find a value for distance but need one, and
2. C - students don't know what "very far apart" means (or at least means for that value)

This is where they are stuck when they first interact with the GTA concerning the Issue. Looking forward, I see that they open the interaction with a question about this (line 112), and that it comes back as their focus after the interaction (lines 166 - 169 and line 191). I do not get any new information to clarify the contents here, but I get more solidification on this content as the students' focus Issue. Figure 4.40 shows the mapping out of the AI and SPI contents into their respective components. The SPI is now colored purple as it is a different focus for the students than the AI.

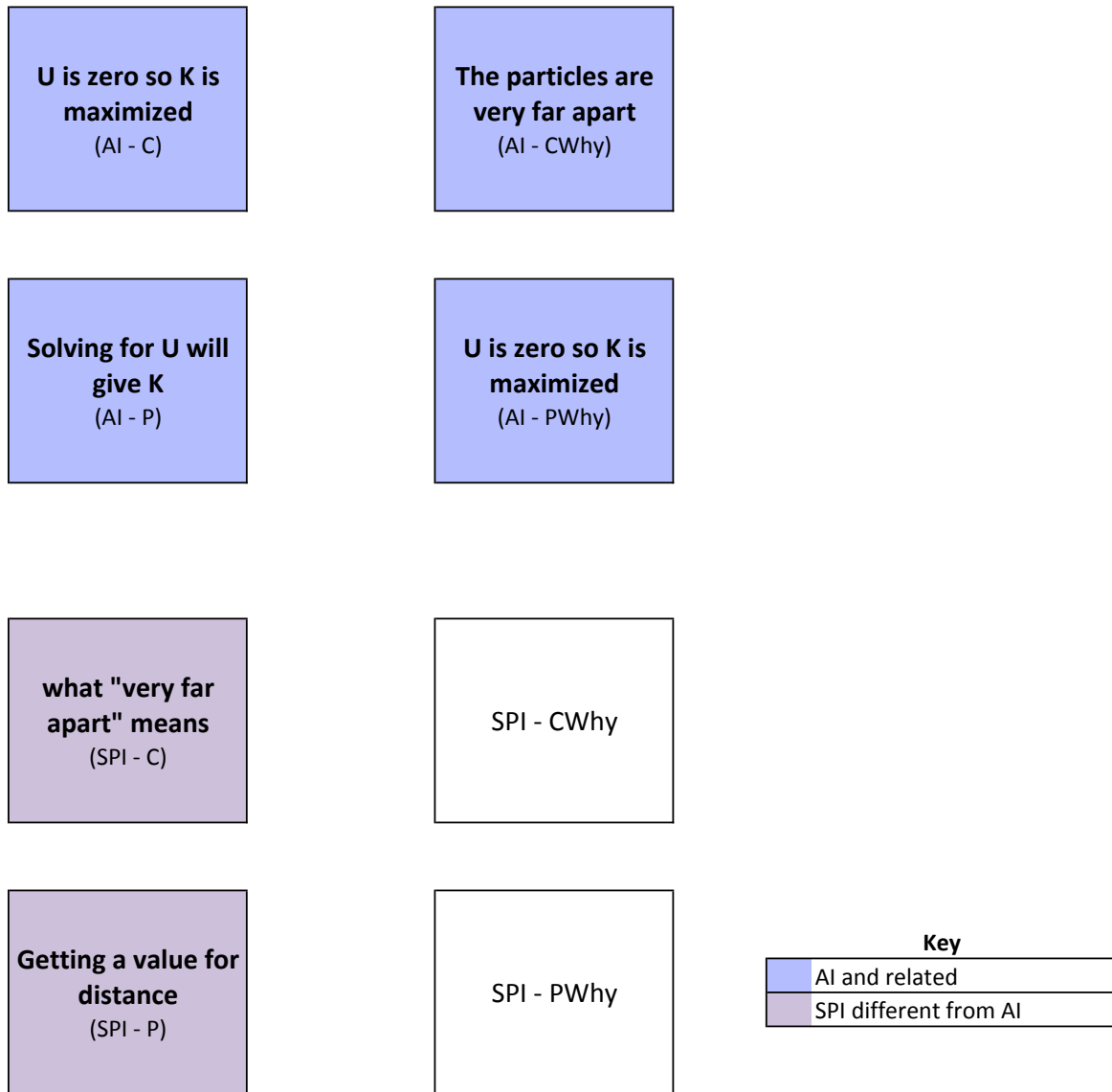


Figure 4.40: The AI (blue) and SPI (purple) are shown filled in with their respective contents. The SPI is a different color from the AI because its contents are different from those of the AI. This is the first and innermost layer of the diagram.

Error (E) and Uncertainty (U)

Examining the AI now, I can see that P and PWhy/C contain Errors. In this problem, U can not be used to find kinetic energy. And, while the statement of reasoning - U is zero so K

is maximized - is true, it is inappropriate to this problem as well. These components contain elements of Error. The CWhy component, however, does not. It is used as initial reasoning in line 88 for solving for U to get K. And it is clarified later as reasoning for K being maximized. However, it is in fact a correct statement and is in itself appropriate to this problem. There is no Error with this component.

I do see Uncertainty in some components of the AI as well as Error. Initially, S2's idea about U being zero comes out as a question (line 88). There is Uncertainty present there, and he decides to go ahead and try it. But the Uncertainty doesn't fully go away. This brings an element of Uncertainty to the C/PWhy component. He begins the procedure with "So if we do - maybe we could just use that equation..." in line 91, a statement that seems to indicate he's trying something but not sure where it will lead. Even as what he does going forward seems to make him a bit more confident, his tone of voice as he confirms his idea to S3 in line 107 with "I think so" does not really indicate that he is certain. It seems to indicate that his idea was the best he could come up with (though he provides more reasoning as to why). These lines are evidence of Uncertainty in the P component as well. Looking finally at the CWhy component, I see that there is no real Uncertainty there. The information from the problem tells them the particles are far apart. They are not Uncertain about that as a piece of the problem. They are Uncertain as to what that means, but that I will account for later. Thus, I have Uncertainty in the C/PWhy and P components.

I turn now to the SPI. I see that at no time before the interaction do the students think themselves in Error of the two SPI components. They are baffled by a lack of value for distance. And they admit to being Uncertain about what "very far apart" means. But they do not think they are specifically wrong in their thinking. There is no Error here.

There is, however, Uncertainty with the C component. S3 admitting to not knowing what "very far apart" means, is an admittance of Uncertainty about this physics content. S2 agrees with her in that Uncertainty (lines 97 - 100). There is also Uncertainty in the P component as the students don't understand what value to put in for distance nor why they can't find one.

This Uncertainty is present when S2 talks about needing an “exact distance” in line 99 after spending time looking for a distance in the problem statement. For each component of the AI and SPI, I’ve now identified Error and Uncertainty as follows:

- AI
 - C - Uncertainty (U) and Error (E)
 - CWhy - neither
 - P - Uncertainty (U) and Error (E)
 - PWhy - Uncertainty (U) and Error (E)

- SPI
 - C - Uncertainty (U)
 - P - Uncertainty (U)

Pre-Interaction: Creation of the AI

Through the descriptions of the contents of the Issue, it might now as well be obvious that the creation of the Issue is Thoughtful, not Automatic (Au). S2 develops the idea that he might use U to find K in steps. It emerges from the notion that the particles are far apart, and so perhaps U is zero. He begins this as a question, even (line 88), and then he decides to try out his idea (line 91 - 94). Furthermore, he has to reaffirm his ideas after S3 questioningly agrees with him (line 107). Determining which elements of Thoughtful Issue creation belong here, I see that S3 did have some influence on S2’s creation, and so the Issue was not created Independently (I). The Issue did, however, begin with a question that went unanswered by the rest of the group. Even though S3 contributes at least some support (lines 103 - 104, 106, and 108), she does not really Collaborate (Co) to help build S2’s ideas, nor does she Challenge (Ch) them. She does, however, ask a question about what “very far apart” means (line 98). While this really plays into the SPI, it is a valuable question to ask as S2 tries to work through his ideas, and so gets included as an Inquiry Question (Qi) for the creation of the AI. Her questioning agreement will

also fall into this category (line 106). With this input, I see that the features of creation of the AI included are an initial Generating Question (Q_{n-a}) that goes unanswered, and Inquiry Questions (Q_i) by another group member.

No component of the AI is Resolved (R) before the interaction. Of the two (PWhy and C being the same) needing Resolution, no ideas or moves are made to Resolve either of those components before the interaction begins. The ideas generating the Issue seem to be more deeply solidified if anything, with the focus of something being wrong firmly planted in the need for a distance.

Neither component of the SPI is Resolved (R) before the interaction. No discussion clearing up the C component really occurs, nor do the students decide on a value for distance. They are still confused about both when the interaction begins.

Now that I have completed discussion of the creation of the Issue, I will look at the building of it in the diagram. I am moving more quickly through this example, and so the next diagram will show the presence of Uncertainty, Error, and possible Resolutions in the inner layer surrounding each component as well as the features of the creation of the AI in the outer layer surrounding the whole AI. These new features can be seen in Figure 4.41

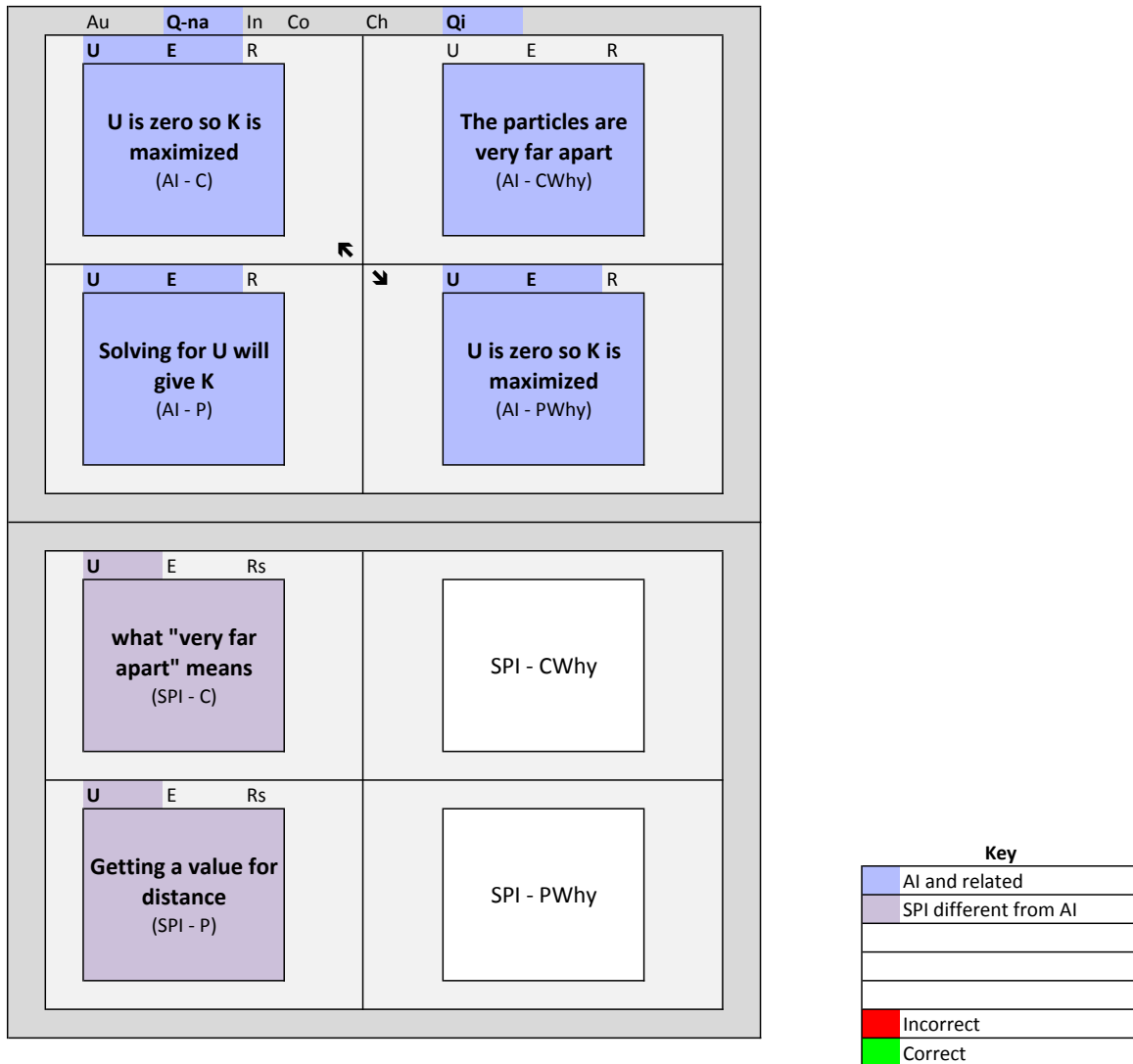


Figure 4.41: The second and third layer have been added to the diagram. The second layer surrounds each component of the AI and SPI. It contains Uncertainty (U), Error (E), and Resolve (R). These are highlighted above components for which they are present. The third layer contains all features of the creation of the AI. Those present are highlighted. All components highlighted surrounding the AI are blue to indicate association with the AI. All highlighted components surrounding the SPI are purple to indicate association with the SPI. The key includes red and green to indicate possible coloring of the R feature, though it is not present here. The diagonal arrows in the center of the AI indicate that the C and PWhy components share the same contents.

During the Interaction: TAFocused Issue Contents (TAFI)

I can move on, now, to how the Issue is treated during the interaction. I'll begin like before by identifying the TAFI. Again, the TAFI has the same four possible components of the AI and SPI. I see the GTA immediately focus on which energies belong in the initial state of the solution after clarifying with the students their intended initial and final states. In fact, she specifically directs them, as a part of constructing their solution, to identify the energies present in the states (line 119). In focusing on which energies are present, most of the attention is given to potential energy not being present and why potential energy is not present in each state. The presence (or lack thereof) of potential energy is a concept and fits in the C component. The reasoning then given for its lack of presence makes up the CWhy component (lines 126, 129, 151, and 155).

I identify the TAFI as having a more specific focus on potential energy. I choose that over a TAFI covering the more general idea of selecting which energies are present for two reasons:

1. The topic of potential and kinetic energies is the general topic of this Issue, and the GTA spends a disproportionate amount of time discussing potential energy over other energies.
2. I attempt, when identifying TAFI's, to be as particular as I can to the contents of the GTA's focus (e.g. potential energy is not present), not just the purpose of the GTA's focus (e.g. which energies are present).²⁸

Finally, at the end of the interaction, the GTA gives directions for what the students should do in light of the presence or absence of energies in each state. She tells them specifically to equate the rest energy of the initial state to the rest and kinetic energies of the final state (lines 157 - 159). This places contents into the P component of the TAFI concerning how to put together their solution. Again, I will be particular and include the specific terms the GTA dictates as needed in each state.

The GTA does not explicitly discuss the connection between the conceptual discussion of energies and the terms needed, leaving the PWhy blank. One might think there is an implicit

²⁸There are adjustments based on the topics and dialogue, but this is generally what I try to practice.

PWhy in that the presence and absence of energies indicates a presence and absence of energy terms. However, during the interaction, the GTA does not specifically focus on a connection, but simply discusses the conceptual, and then directs the procedural. Imposing a PWhy component here is inappropriate.

The TAFI then reads as follows:

- C - There is no potential energy
- CWhy - PE_i is zero since there is only one object, and PE_f is zero because the two objects are far apart
- P - energy terms to equate, specifically RE and KE
- PWhy - blank

During the Interaction: Student Response to TAFI

The students' response to the GTA seems to be one of some confusion and going along with what they're being told. S2 is unable to correctly answer several of the GTA's questions (lines 123, 125, 144, and 146) but seems to only pick out correct answers when they are the only options left (lines 139 and 152). He and S3 go along with these answers as if cataloging them, rather than engaging with the ideas. He answers in quiet tones and uses a lot of "Okay"s as well, indicating an acceptance without really understanding (lines 127, 131, 134, 142, 148, 156). S3 also contributes to identifying the correct answer by reading the GTA (line 128) or identifying the remaining option (lines 140 and 150). With these behaviors, it seems the students do not really Get (Get) the TAFI.

There is also no evidence that the S2 (or the others) try to take the GTA's information during the interaction and Rectify (Rectify) it with their own ideas. They follow along, hinging on the GTA's guidance the entire time. They also do not try to Redirect (Redirect) the GTA to talk about something else. They do not come back around to their question about the distance between particles or anything else related to their Issue.

Finally, there is no evidence that the students really Resolve (R) what the GTA focuses on. They follow the GTA, trying to answer the questions and okay-ing in agreement during the interaction. They do not seem to be able to make any modifications to moves or ideas with what she says during the interaction. A quick glance at the dialogue after the interaction shows that S2 does follow the GTA's direction of including two rest energy terms by multiplying their RE_{final} by 2. However, this is not so much a Resolution of the TAFI as it is a following of directions that only encompasses one small piece of the TAFI - P. Thus, there is no Resolution of the TAFI.

With the TAFI and students' response to it analyzed, I add these features in to the diagram. Figure 4.42 shows the TAFI and responses added in. Here, the TAFI is colored orange in all components. No component really matches the AI at all. All response features are listed, but none highlighted as I saw no evidence of their presence.

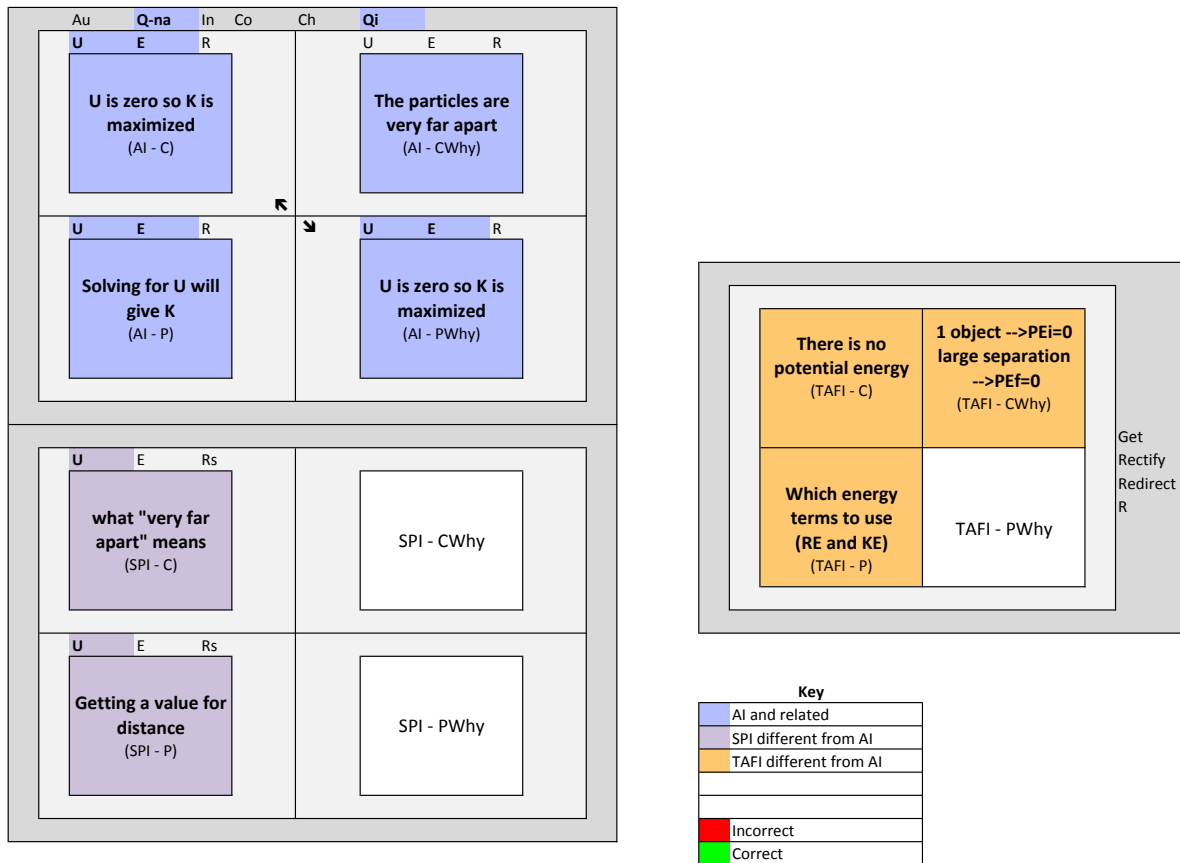


Figure 4.42: The first, second, and third layer of the TAFI have been added to the diagram. The contents of the TAFI fill their respective components in the first layer. It is highlighted orange to indicate it is different than the AI. The third layer is added with all student response features. None are highlighted indicating none exist in this example. Orange is added to the key to differentiate the TAFI from the AI when they are different. All TAFI specific features would get highlighted orange.

During the Interaction: Address of Issue Components

Even though the TAFI is different from the AI and SPI, whatever is discussed may still Address components of the AI and SPI. I note that the focus of the interaction is on which energies are present in each of the initial and final states. There is a final focus on the equation one should use to solve this problem. I will look at each component of the AI and SPI to analyze if and how it has been Addressed (Address) by the interaction.

The AI - P would be Addressed with discussion of moves and concepts behind them. The dialogue that involves specific moves tells students to equate $RE_{initial}$ to RE_{final} plus KE and to use two RE_{final} s (lines 157 - 159). While it might at first seem like this Addresses the students' procedural component by telling them what to do instead of using potential energy, it actually just tells them what they are already trying to do about kinetic energy. S2 has already written out that initial rest energy equals final rest energy plus kinetic energy. However, he then decided that potential energy needed to be put in for the kinetic energy term in order to find kinetic energy (Figure 4.38). What the GTA told them to do does not go far enough to actually Address the AI - P.

Looking at the AI - PWhy/C, I see a similar thing. Identifying which energies are present in the initial and final state does in fact reiterate that U_{final} is zero (lines 150 - 154). However, it does not deal with K being maximized as a result of U being zero. Thus, while a small piece of this component is confirmed in the interaction, this component is not Addressed.

I see a different story with AI - CWhy. As the GTA addresses the energies present in the final state, she follows the reasons the potential is zero. She explains that the objects are very far apart (line 151). This brings up the CWhy, but does not yet Address it. It is only Addressed as she follows through with explaining that the particles can not interact when they are very far apart (line 155). This adds new reasoning information to the CWhy, Addressing it with a Conceptual (Conc) idea.

The fact that CWhy is Addressed may not help the students with their Issue because they did not originally have an Error or Uncertainty with this component. But the component was

in fact Addressed. Briefly, seeing as there was nothing to Resolve (R) or Shift (Shift) here, there is no Resolution, Functional Resolution (Rf), or Shift in this component.

I will look at the SPI as well. After S3's initial question about what to use for the distance (line 112), there is no specific talk about any value for distance or what might be used. Nor is there any talk that really deals with the SPI - P later on. It is not Addressed after being brought up. However indirectly, the SPI - C is Addressed. This is done with the same information used to Address the AI - CWhy. It is revealed indirectly that "very far apart" means that particles can not interact (line 155). Again, this might not help the students as they seem to understand this at some level but have trouble connecting the idea to their actions. But it is considered Addressing the component with a Conceptual idea. While there was a chance to Resolve some Uncertainty here, it appears, from S2's response of "Okay," (line 156) that there was no real Resolution for the students. A brief look at dialogue afterward confirms this (lines 166 - 168).

Looking now at what has been Addressed and how, I see the following:

- AI
 - C - none
 - CWhy - Addressed (Address), Conceptual talk (Conc)
 - P - none
 - PWhy - none

- SPI
 - C - Addressed (Address), Conceptual talk (Conc)
 - P - none

During the Interaction: Starting Issue and Other Student Actions

Before showing the next stage of the example diagrammatically, I will quickly identify which Issue began the interaction. I look to the first few lines of the interaction and see S3 asking a

question specifically about what value the students' should use for distance in their potential equation (line 112). This is the SPI - P, and so the SPI began the interaction.

Looking briefly to what else the students might have done during the interaction, I see that most of the features depend on them Resolving a component of the Issue to begin with. The students could not Move forward (Move) or Restart (Restart)²⁹ their problem as they did not Resolve a component. Thus, they could not also have Demonstrated (Demo) understanding during the interaction by definition. They could have expressed Feelings, but there is no evidence of that happening during the interaction either. Thus, none of these other action features apply to this example. The diagram for the addition of these features can be seen in Figure 4.43.

²⁹In the absence of both Move and Restart I put M/R in the diagram.

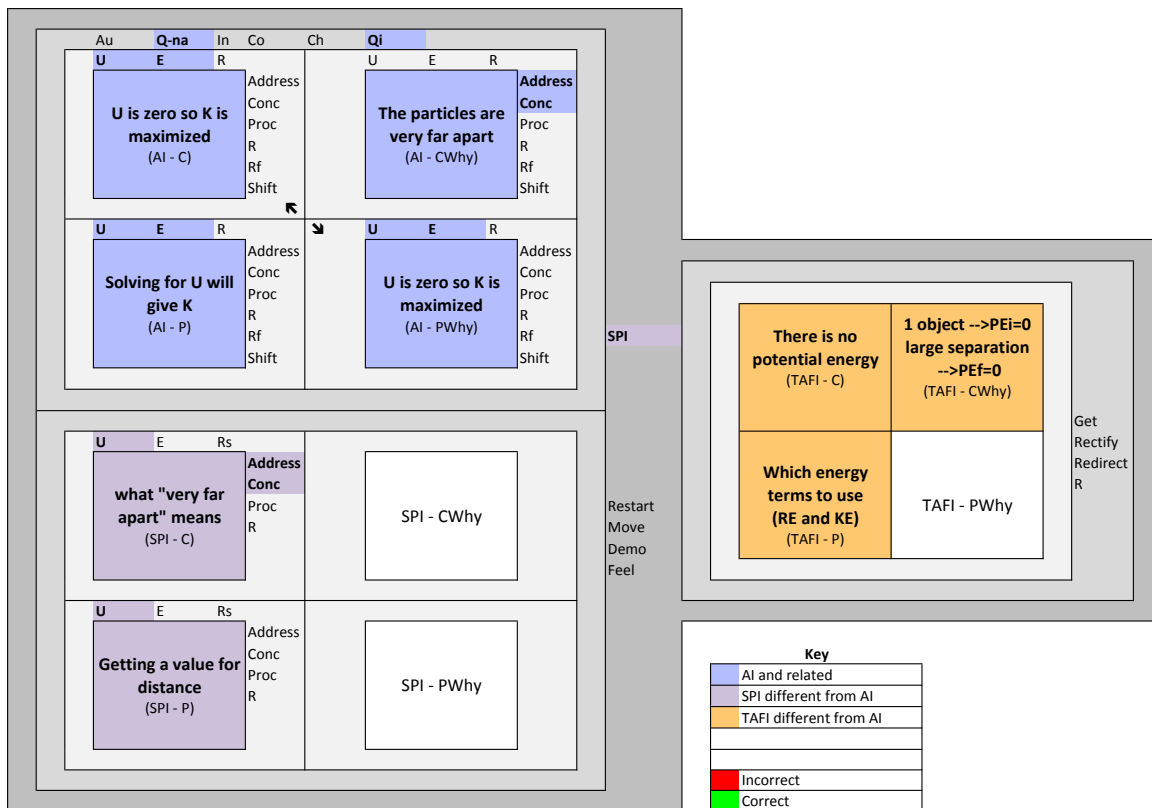


Figure 4.43: The diagram now contains the fourth and outermost layer. Features have been added to the middle column of this layer to represent other student actions during the interaction and which Issue began the interaction. SPI is present and highlighted purple here to indicate it was the beginning Issue of the interaction. The remaining features - Restart, Move, Demo, Feel - further down are not highlighted, indicating they are not present. Additionally, all features addressing the Issue components are added along the right sides of each component of the AI and SPI. Those that are present are highlighted accordingly - Address and Conc for the AI - CWhy; and Address and Conc for the SPI - C.

Post-Interaction: Resolution and Other Student Actions

I will continue to stay with the Issue and how it proceeds after the interaction. As I did before, I'll return to talking more about how the GTA interacts with students during the interaction after this section. I first identify whether any component of the Issue is Resolved (R), Functionally Resolved (Rf), or Shifted (Shift) after the interaction.

I see that the first comment after the interaction is made by S2 and acknowledges that the interaction did not help them with the problem they were having (line 161). S1 chimes in that they need kinetic energy, but seems to be ignored by the S2 and S3 (line 162). S3 then returns to talking about the SPI that she began the interaction with, still confused about what value to use (lines 166 - 168). S2 then returns to the AI to hash through it again (lines 169 - 180). S1 interrupts once more to describe one possibility for how the group could treat their potential term (line 172) but is met with confusion by S2 (lines 172 - 174). S2 already knows potential is zero. He is simply using the formula to try and find kinetic. So far, I see no Resolution of any components of either the AI or the SPI. I only see a restatement of the components of both the AI and SPI, with seemingly more confusion than before. There seems to be a slight change for S2 in lines 178 - 180 as he questions how to figure out kinetic energy at its maximum. Before, he was trying the formula for U, but at this point he seems out of ideas.

Following the discussion a bit later, S3 expresses a bit of confusion at the formula for potential (line 182 - 186). Her confusion prompts S2 to fully share his ideas, the AI, once again to clarify what he was trying to do. In doing this he comes to the conclusion that his idea must be wrong in some way because the problem does not include the necessary information to follow through with his plan (lines 187 - 191). They will have to find a different way to solve the problem. Though, again I recognize a deeper change in S2's thinking, there is no Resolution to any AI component, but rather a resignation of S2's original ideas.

There is no Resolution to any component of the SPI either. Though S2 now recognizes the group will not get a value for the distance, this is not considered Resolved. It is also a resignation of something he'd like to do but can't, not an understanding of what the value for

distance actually is. I do not see further evidence S2 or S3 has internalized the idea of “very far apart” to really recognize it’s significance. They are still Uncertain about what to do with it to find K, and so it too remains unResolved.

There are no Resolutions, then. Nor are there any Functional Resolutions as no student is able to Resolve the Issue and Move the group forward through the problem (though S1 puts in an effort). But there are certainly changes in thinking happening, and those are important to address. I will examine whether these changes are specific Shifts in the AI components. As I mention above, by the end of the segment, S2 expresses his entire idea again, restating the AI (lines 187 - 190). He then comes to the conclusion that it must be wrong (or at least something about it must be wrong) because the problem does not give the information the students need to use his approach (line 191). With this admittance, S2 changes his focus from trying to make his idea work to recognizing that it won’t work and needing a new idea.

This seems to be a change in the AI - P component, since S2 realizes that he cannot use U to get K. However, this change is not a Shift from Uncertainty to Error or Error to Uncertainty (the kind of change that I acknowledge with the Shift feature). It is a change from Uncertainty to certainty. S2 changes from being Uncertain about his move (AI - P) and focusing on needing a value for distance (SPI - P) to being certain that his move is Erroneous and focusing on the fact that his strategy is wrong (new SPI - P) because the problem does not provide an exact value for distance (new SPI - PWhy). There has not been a Shift *within* any single component as is required by that feature. There has been an actual change of some of the Issue contents to something other than what I started with. This is not accounted for by the Shift feature, and so I do not mark this as a Shift. Changes of this kind get dealt with differently which I’ll review below in “Issue Changes: Multi-Interaction Issues” on page 220. The job of identifying the presence of any Resolution features for this example is complete, and so I’ll move on.

While I see no Resolutions after the interaction, I *can* pick out other actions the students did after the interaction.

- The students were not able to Move forward (Move) as they were still dealing with the

exact same Issue in the exact same way. They also did not Restart (Restart)³⁰ any of their solution. Rather, they stayed in the same place, unmoved by the interaction. This is evidenced in lines 166 - 180 where S2's and S3's dialogue indicate they continue discussing the same AI and SPI components.

- The students do not continue Discussing (Disc) anything from the interaction. In fact, they leave the information of the interaction and return to discussing their Issue as it was discussed before the interaction (though S1 has more input in a different direction this time).
- They do Demonstrate (Demo) understanding of information from the interaction. They follow the GTA's directions by multiplying their RE_{final} by 2, Demonstrating that they understood, at least in part, what was meant by having two rest energies.
- Finally, they also express their Feelings (Feel). They specifically state that the interaction did not help them with what they were doing (line 161). In my definition, this is an expression of Feelings about the helpfulness of the interaction.

Figure 4.44 shows the features listed after the interaction. This completes the analysis of the Issue in this example. I will move on to examine a bit more deeply how the GTA interacts with students during the interaction.

³⁰In the absence of both Move and Restart, I put M/R in the diagram.

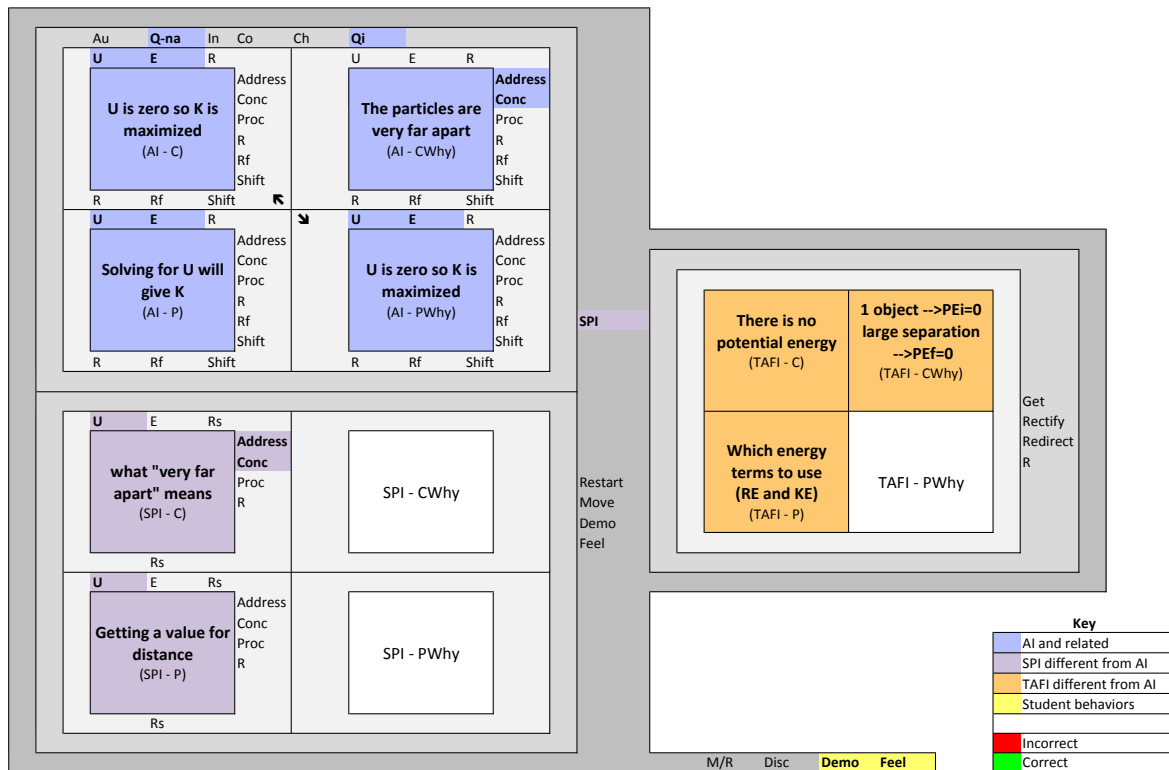


Figure 4.44: The diagram now shows all features possible after the interaction. The resolve features - R, Rf, and Shift - are added beneath each component of the AI and SPI. None are highlighted as none are present. The other action features have been added in the extension of the outer layer at the bottom of the diagram. Of the four possible, Demo and Feel are highlighted to show their presence. These are yellow indicating they are behaviors by the students.

During the Interaction: Who Begins

Looking at the first dialogue in the interaction, I see that it is the students who begin the interaction (SiStart), as they are the first to begin talking (line 112). In this case, the students also begin the topic of discussion on their SPI. The GTA redirects the students' focus to a different topic as identified by the difference between the TAFI and AI. But this redirection is still for the purpose of Addressing the students' Issue, however off the mark it might be. Evidence of this can be seen in the first few lines as the GTA first listens to S3's question in line 112 and then clarifies some of the students' intent in line 115. The GTA spends some time identifying what she thinks is the Issue, and then Addresses that. Thus, it is the students who begin this

topic (SiTopic).

During the Interaction: Diagnosis

In this example, the GTA does not spend anytime near the group before the interaction begins. The GTA is met with an opening question by the students on the value for distance (line 112). The GTA then asks a clarifying question of the students about their intended initial and final state (line 115). Once the students answer this question, the diagnosis is over, and the GTA immediately begins helping them with an Issue (line119). This would seem like an Abbreviated diagnosis. But given that the GTA's chosen topic seems a bit of a stretch to jump to from the initial round of questions and answers, I will take another look at the diagnosis.

When beginning to help the students, the GTA looks at the whiteboard and begins talking about the kinds of energy present in each state (line 119). This topic is a bit of a divergence from the initial question asked by S3. It is not a topic that would necessarily naturally follow S3's question if the only information the GTA had gathered while diagnosing was from that question, or even that question and the GTA's follow up clarifying question. It would seem the GTA is also putting together information from her clarifying question and the whiteboard work of the students. In fact, without further probing, the students' whiteboard work in Figure 4.38 shows the (almost) correct energy terms for a solution involving states c and a rather than the required states c and b (as shown by the problem diagram in Figure 4.39). This would be reason enough to clarify with the students their intended initial and final state, diagnose that the intended states and energy terms do not match, and move forward with helping the students to identify the correct energy terms to use. This topic would be a bit of a stretch if jumped to from S3's initial question about distance. Thus, Abbreviated does not seem to fully fit the most logical interpretation of how the GTA diagnoses. The GTA must diagnose using the students' work as well as through the Abbreviated questions and answers. This diagnosis, then, is done through looking at students' work (Work).

During the Interaction: Who Directs and How

Reviewing the dialogue after the diagnosis (ending at line 118), I see clear evidence of the GTA directing (TAdirect) the interaction and seeking students' input (Sinput) as she does so. She has chosen the topic and controls the flow of the conversation by focusing on the initial state and asking questions, then focusing on the final state and asking questions. The students follow her lead, attempting to answer her questions, and continuously confirm what she says. In this way, they participate in her discussion, and do not direct it themselves.

There is strong evidence of her encouragement of student input as well. She attempts to guide the students through identifying the appropriate energies in each state by first telling them that is the focus (line 119), and then asking them to identify the energies (lines 122, 135, 138, and 143). The student input she seeks is correct responses to targeted questions, and she typically uses conceptual information to correct a students' incorrect response without additional questions (lines 126, 129, 149, 151, and 155).

However, I acknowledge that in one instance, she asks the student a probing question for the thinking behind his response. This happens in line 124, when the GTA asks S2 "Why?" after S2 states that there is potential energy in the initial state. And S2 obliges by telling the GTA that there is potential "because it doesn't have any kinetic." In his honest answer, S2 shares an idea the GTA prompted (Prompt) him for. I'll note that after this sharing, the GTA immediately returns to adding more information to the discussion to correct the response, rather than continuing to explore the student's idea. But there is an initial prompted sharing of the idea that should be noted. To summarize, the features seen in how the GTA interact with students are:

- Starts Interaction - Students (SiStart)
- Starts Topic - Students (SiTopic)
- Diagnosis - Work
- Who Directs - GTA (TAdirect)

- How Directs - Seeking students' input (Sinput)
- Students Share Ideas - Students do share ideas, prompted by the GTA (Prompt)

This brings the framework of the second example to a close. But before I reveal the final diagram, I label it with the content category of the Issue.

Issue Content Category

Students are attempting to set up the appropriate terms to use to solve for their kinetic energy in this example. They reveal ideas about how the physics work such that they can try to use potential energy to get to kinetic energy. They then attempt to do this. I recognize that these students do not seem to use variables but write in numbers for each quantity outright. However, the focus of the AI is not on the values and calculations as such, but on the strategy itself. This fleshing out of physics ideas and a strategy for finding kinetic energy falls into the Solution Approach category. Figure 4.45 shows the final diagram, fully labeled, for this example.

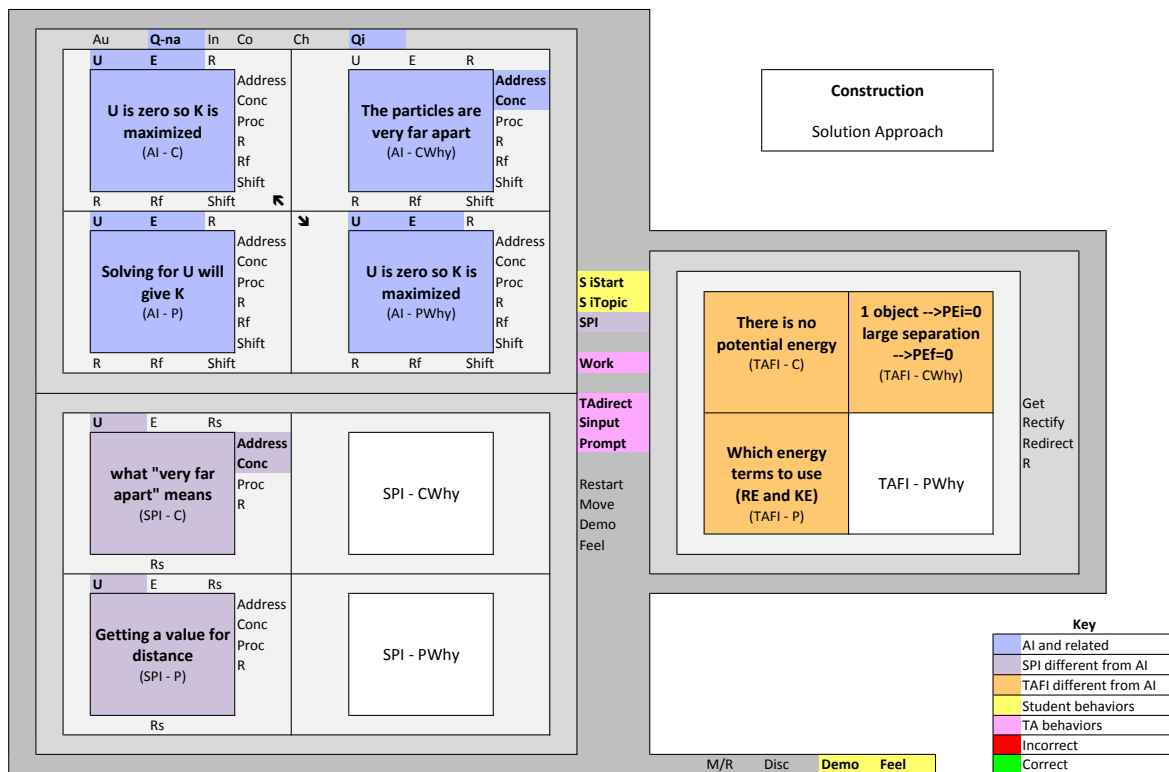


Figure 4.45: The final complete diagram shows the rest of the interaction features filling the middle column of the outermost layer. Who started the interaction and topic shows S iStart and S iTopic and are colored yellow indicating they are students behaviors. The diagnosis is Work, colored pink indicating a GTA behavior. Who directs and how show TAdirects and Sinput to show the GTA directs the interaction and includes student input. The feature indicating whether or not students share ideas shows Prompt indicating the students shared an idea after being prompted by the GTA to do so. These are all pink indicating they are GTA behaviors. Pink is also added to the key showing all features with that color as GTA behaviors. The Issue content label shows that this example Issue is one of Construction: Solution Approach.

Issue Changes: Multi-Interaction Issues

I ended the post-interaction analysis of Resolutions and Shifts after identifying that neither existed for the present AI and SPI components. However, as mentioned, there was a major change that occurred for S2 that led to a change of Issue contents. I return to that change now to discuss what I do with it, since I didn't allow it to be extracted in a meaningful way within the framework for that example.

I'll first restate what occurs for S2. S2 changes from being Uncertain about his move (AI - P) and focusing on needing a value for distance (SPI - P) (lines 88 - 89, 99, and 167) to being certain that his move is Erroneous and focusing on the fact that his strategy is wrong (new SPI - P) because the problem does not provide an exact value for distance (new SPI - PWhy) (line 191). As S2 changes his view of what the Issue is, he changes the contents of some components of the Issues themselves.

In addition, at the end of this data segment, the students are still stuck. Not only do they change their ideas, but nothing is Resolved, and the students can not Move forward without having a new strategy. The point at which I cut off the transcript is clearly not the end of their Issue.³¹

Now, if they had developed a new strategy on their own, I would have added any appropriate dialogue into the post-interaction section of the transcript and analyzed it above accordingly. But they do not come up with a strategy on their own. Instead they have another interaction with the GTA before they can Move forward with their solution construction. This second interaction marks the example as the first part of a multi-interaction Issue (two interactions to this Issue).

The data segment I just analyzed ends right before that second interaction begins. The post-interaction dialogue, then, is also pre-interaction dialogue for a second data segment on this Issue. It is in developing a second data segment to include the second interaction that I

³¹I know this because all students eventually finish every lab, and these students are nowhere near finishing this problem, nor can they Move on with it as it presently stands. I end the transcript for this data segment just before a second interaction with the GTA begins.

will account for the changes I analyzed. I begin the second data segment at the end of the first interaction, and I end it when the Issue is officially over. The contents of the AI and SPI will be determined via the same strategy I have been using, which will draw out the changes I've identified in S2.

Multi-interaction Issues account for 25% of the data segments in this study. Aside from the fact that I divide an Issue into multiple data segments when there are multiple interactions, there are no differences in how I analyze those segments (though I generally expect the Issue to remain unResolved until the last data segment). Each one is analyzed as I have done above. Thus, there is no need to further discuss the analysis these kinds of Issues or the example separately from the rest of the data. If such a need arises to distinguish them later, I will do so.

4.1.9 Framework Limitation: Problem Type

The Issues Framework emerged out of an analysis of data from two kinds of analytic problems: (1) back-of-book problems with fairly extensive problem statements, and (2) straightforward directive problems asking the solver to find a particular quantity (typically using collected data). While I think the generality of the framework may make it useful to a larger selection of problems (something I discuss further in Section 6.3.2), there is at least one particular kind of problem the framework is not currently designed for - multiple choice or multiple select problems in WebAssign.³²

I initially attempted to use the framework to examine students' Issues regarding multiple choice and multiple select conceptual problems. However, during these problems students went through the process of creating an Issue while discussing the problem, selecting an incorrect answer, and checking it with a WebAssign submission. They would then repeat the process until they had only one or two submission left, at which point they interacted with the GTA.

Often, each round of reasoning and selecting an answer involved the creation of a different Issue as they tried to get the correct answer. Yet these Issues were not mutually exclusive

³²This may be applicable to all electronic homework systems that grade problems immediately and allow multiple chances. This study was only conducted on problems for which the answers were selected in WebAssign.

either. They built on each other, creating a history of inappropriate reasoning and ideas. It was not possible to put all that history concerning the problem into one framework diagram, and yet it was also inappropriate to separate them into multiple diagrams, as too much of the students' process was lost by dividing them. Thus, this particular framework is not appropriate for examining those kinds of problems. It is possible the framework may be appropriate for examining multiple choice and/or multiple select problems that are not based in WebAssign. I did not have the ability to check that in this study, but it should be done in future research. It is also possible there are other kinds of problems the framework is ill-suited for. Future research should examine Issues from a wide variety of problems using the framework to better define its usefulness.

4.1.10 Using the Issues Framework

While the framework and the process it describes are complex, the diagrams produced are visually friendly and allow for easy pattern matching. One can identify bigger differences at a glance as well as sort them easily by any particular feature, content category, GTA, or physics problem. In Chapter 5, I discuss results of my own sorts of the diagrams, describing the stories revealed in each Issue content category. In this section, I model one visual pattern-matching process possible with these framework diagrams. I sorted them by content category and have placed six of the eight Unit Conversion Issue diagrams from my dataset together in Figure 4.46 as a sample.

I begin reviewing these diagrams by looking at the quantity of colored components in the AIs and TAFIs. This gives me a general sense of how complicated are the Issues in this content category. Reviewing the diagrams, one can see that five of these six diagrams have AIs with only P components. Similarly, the TAFI has only P components as well. This tells me that the Issues are more simple and only focused on procedure. I also notice the one AI that contains both a P and PWhy component, and I make a mental note to review its specific contents in more detail later. This structure allows me to easily identify these kinds of outliers for deeper analysis.

Next, I review the colors of the AI and TAFI and see that, except for the one outlier, the colors match, indicating the GTA has focused on the Issue that needs addressing. In the case of the outlier, the color is mixed, so I know the TAFI is still almost a perfect match.

I review the SPIs in this category, and I see that half of them are blank. I set that half aside, knowing with that glance that the students do not realize they have created an Issue. I turn to the colored SPIs. The outlier is colored the same as the AI telling me the students are aware of their Issue. In the remaining two Issues, both SPIs are purple, indicating a different SPI from the AI. I suspect this comes from students submitting an incorrect answer to WebAssign, since I know they have created these Issues while executing their solution, but I'll make a note to check the Issue contents later.

I look next to the central column to note the distribution of colors. A lack of yellow indicates the GTA was beginning and directing the discussion, though the GTA might still have included students. A strong yellow presence means different things depending on which height in the middle column it is located.³³ These diagrams seem to show a mix of colors. The location of the colors tells me that the students began the interaction in five of six cases, as the top cells in the column are yellow. Looking down, the middle grouping of cells is pink, indicating that the GTA directed the interaction. Where the pink is only one cell thick, the GTA did not encourage student input. Where it is more than one cell thick, the GTA did encourage student input. A

³³Yellow at the top means students began the interaction. Yellow in the middle means they directed it, and yellow at the bottom means they continued with the problem before the interaction ended.

glance at that particular group of features tells me the GTA encouraged student input in two of six cases. Finally, I notice more yellow in the bottom group of features in another two of six cases. This reveals that the students continued on in executing their solution before the interaction had ended.

So far, I've let my eyes wander around the page and mostly pulled out patterns and outliers from the largest and most central features. Getting a little more focused now, I can learn a bit about the temporal pattern of the Issue by looking clockwise around the diagrams. To identify features before the interaction, I look along the tops of the AI components and along the top of the overall AI (one layer out). While I may not be able to read each letter, I see that the center cell above the AI - Ps is highlighted in all cases. I also notice that the left-most cell above the overall AI is highlighted in five of the six cases. I may not remember exactly what those features are, but I can check on that. What the diagrams reveal easily is that these features are present in all or almost all cases.

Looking to the right side of the AI - P component tells me if and how the Issue was addressed. After reviewing many of these diagrams, I recognize that a top highlighted cell, followed below by an unhighlighted cell, and then another highlighted cell reveals that all of these Issues were Addressed with Procedural talk only. Additionally, the green Resolution cell stands out, and the location of that green cell will tell me when the Issue was resolved. A quick review of the right side and bottoms of the AI - P components reveals that the Issue was fully resolved during the interaction in four of six cases, and after the interaction in the remaining two. I make a final note to review those last two cases in more detail to better understand the path of the Issue.

Finally, I glance at the bottom right arm to identify what the students do after the interaction. I notice immediately that Move forward or Restart are highlighted in all cases (the left-most cell is highlighted). I'll check later whether it is specifically Move or Restart. The visual value is that this cell is highlighted in all cases, meaning students were able to continue progressing, one way or another, after the interaction. They also either continue a Discussion

or Demonstrate understanding in five of the six cases. I can tell this by noting that multiple cells along the bottom are highlighted, and that the right-most cell (Feel) is never highlighted.

Reviewing the framework diagrams visually, I gather quite a bit of information about the students' process creating the Issue, the process during the interaction and nature of some of the characteristics of the interaction, and how the students' process continues after the interaction. While I can not gather all the details I might want from the framework, due to the framework's structure and coloring, I *can* map out a fairly complete story just by reviewing the highlighted features. This makes the framework and diagrams a very useful tool for quickly pattern-matching important pieces of a complex process.

4.2 Coding

Once the framework was fully formed from the initial sample of data, I developed a set of sorting tasks and a survey to apply the framework to the remaining data. The sorting tasks were used to code the Issues Content Categories and the Characteristics of the Interaction. A survey was designed to code the rest of the framework's features. All coding was also done with a second researcher to test reliability and validity of the framework. I discuss the details of reliability and validity of these coding tasks in Section 4.3

Issue Content Categories

I sorted the data segments into Issues concerning Construction and Issues concerning Execution. Each group was then sorted further into Getting Started and Solution Approach, and Unit Conversions and Other respectively.

The data segments were sorted into their content categories based on the transcription from before the interaction only. This ensured that the content categories applied to the students' actions and expressions prior to the GTA's influence. This transcription was taken from the data segments as described in Section 3.5.1. Segments that did not have an Issue were identified and left out of the sorts. These segments did not have transcription pertaining to any Issue,

and so could not be sorted accordingly. Complete instructions for this sorting task can be found in Appendix B.

Characteristics of the Interaction

I used another series of sorting tasks to code the following features: who started the interaction (iStart), who selected the Issue topic (iTopic), how the diagnosis was conducted (Diagnosis), who directed the interaction (Directs), how the interaction was directed (HowD), whether the students shared ideas (SShare - present or absent), and how the students shared ideas (SShare - Prompt or Own). Each feature was coded through a single sort of the data segments. I used data segments adjusted from those described in Section 3.5 along with the video of the data to complete the sorting tasks. Complete instructions for the sorting tasks can be found in Appendix B. Below, I briefly discuss how I modified the data segments to focus this task.

Data Segment Modification

The data segments for these tasks were all excerpts from the original data segments. These tasks only focused on the interaction and whether the students hands were raised or whether the GTA was in the camera's view. Thus, to focus coding, only that particular part of the original data segment was extracted for these tasks.

Furthermore, sorting tasks required that a researcher focus on two different areas of the reduced data segment at different times. To focus attention appropriately, the segment was further partitioned into a top and bottom section. The top section covered the time the GTA entered the camera's view to the time the GTA finishes the diagnosis of an Issue (signified by pink timestamps). The bottom section began at that moment and went until the end of the interaction (signified by cyan timestamps). Using the example from the ball toss problem, the reduced data segment can be seen in Table 4.1.

Table 4.1: Sample Transcript for coding Interaction Characteristics

Time	S1	S2	S3	GTA
0:18:47			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:48			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:49			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:50			(writing $1/2 mv^2_f - 1/2 mv^2_i = 0$)	
0:18:51			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:52			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:53	zero		(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:54			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:55			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:56			(writing $1/2 mv^2 = 1/2 mv^2$)	
0:18:57				why is the work done zero?
0:18:58				why is the work done zero?
0:18:59		hmm?		why is the work done zero?
0:19:00				why is the work done zero?
0:19:01		it's not?		
0:19:02	no			
0:19:03	it's not zero			
0:19:04			It won't be zero?	
0:19:05				
0:19:06				
0:19:07		work equals		
0:19:08				
0:19:09				
0:19:10				
0:19:11				
0:19:12		I can't remember the formula for work (mouse)		
0:19:13				
...
0:19:33		plus F y delta y		

There is one exception to the above rule marking the end of the bottom section. In cases in which a GTA-student interaction is cleanly divided into multiple topics (covering more than

one Issue), the bottom section, that normally ends at the end of an interaction, will end instead at the end of that topic.

Also, in the case in which an interaction covered multiple TAFIs and there were no clean divisions - a switching back and forth - the same reduced data segment was used for each TAFI brought up during this part of the interaction. Thus, the resulting features in the diagrams are not necessarily unique to a particular Issue. This does not happen often, but where it does I note it specifically when discussing results in Chapter 5.

Survey to Code Remaining Issue Features

Through my analysis, the Issues Framework emerged as a structure of features where almost every one was either present or absent from each data segment.³⁴ To now use the framework to code a larger sample of data, I needed a tool that allowed me to treat each individual feature as its own coding dimension with the categories “present” and “absent”. Additionally, I wanted to be able to guide a coder through coding only the necessary pieces of the framework. For instance, if a PWhy component did not exist for a particular data segment, there was no need to additionally code every feature particular to that component. The coder should be able to skip over coding all those additional features.

Initially, I thought about coding through a series of sorting tasks (as described above). A series of sorting tasks would have allowed me to code each feature separately for all data segments, something that was appealing given the complexity of the entire framework. However, this would have required a minimum of 50 different sorts of the data. Also, due to the need for the different sorts to be dynamic in nature,³⁵ the path through the sorting tasks would have to be very carefully monitored for each segment, increasing the chance for human error. This made sorting tasks inappropriate for the coding needs.³⁶

³⁴Most features that do not fit this description were coded using sorting tasks as described above.

³⁵If a coder sorted for the presence of a particular parent feature, those segments with that feature present would then be sorted again for daughter features, while the other segments might take a different path through the different tasks.

³⁶If a researcher were interested in further examining a small subset of features, coding by sorting tasks may be the most efficient method to use.

I instead turned to the idea of writing a survey with a series of questions that asked about the presence of each feature. A survey would allow me to ask “yes”/“no” questions for the presence or absence of features, would allow me to order the questions easily, and could be made dynamic to lead coders down different question paths. One downside to a survey is that a coder would have to take the whole survey for each data segment, rather than coding each feature individually. This meant that a coder would get very accustomed to the survey as a whole, but may not become familiar with each feature and its definitions quickly, as could be done with sorting tasks. However, I expect this could be overcome with a large enough sample of data.³⁷

I developed a survey in Qualtrics³⁸ to code the remaining features of the framework. While Qualtrics is not specifically designed for coding data, several of its features provided the means to create a coding survey that met my needs: the ability to chunk questions into different labeled chapters (called “blocks”); to place questions in a loop, allowing me to ask the same questions multiple times about the different Issue components; and to skip questions or entire chapters of questions using a variety of design logic statements, giving the survey the dynamic nature required. Additionally, I added a table of contents that allowed one to return to previous chapters in the survey to redo questions.

Qualtrics allows for individual HTML, CSS, and JavaScript additions as desired by the survey designer. Using this freedom, I placed instructions for each question in a right sidebar, a detailed status list by chapter in the left sidebar, and examples below the main question and answers. This layout can be seen in Figure 4.47.

Finally, Qualtrics allows survey responses to be exported in csv format for easy processing. Using this export file and Excel, I was able to quickly check agreement on each data segment while working with another coder as well as automatically populate the appropriate features in each framework diagram.

The survey has 146 possible questions. Initial questions require coders to enter a data

³⁷This study used a relatively small sample size.

³⁸<http://www.qualtrics.com/>

segment ID. I added my own initials to the end of the ID to differentiate my final survey from that of other coders. Each following question in the survey pertains to a specific feature of the framework. Instructions for how to answer each question are embedded into each survey question along with examples of dialogue representing each feature. Instructions for how to approach taking the survey in general were included with the data segments to be coded using the survey. A copy of those instructions and a list of all survey questions, instructions, and examples given can be found in Appendix B. Additionally, questions were chunked together into chapters based on different pieces of the framework. For instance, all questions concerning how the Issue was created were contained in one chapter. This chapter had a title that showed in the table of contents as well as in the left status sidebar.

I designed the survey to guide a coder through the framework based on responses to particular questions. For instance, if a coder decided that an Issue was created Automatically, the survey skipped all questions related to Thoughtful creation only. This helped the coder avoid confusion with repetitive or unnecessary questions. Thus, even though the survey had a large number of questions, many of them were skipped over in each data segment.³⁹

Each question was given its own page in the survey so that the coder's attention was isolated to that particular feature of the framework. This has the benefit of focusing the coder's attention, but it also removes the bigger picture of the framework that might help the coder situate a particular feature. This bigger picture could be added back by accompanying each data segment with an outline of the framework diagram. The diagram was completed after all the data had been coded, and so was not included during coding in this study. Figure 4.47 shows an example of what a survey question looks like.

³⁹No more than 60 questions were answered for any single data segment in my sample. More often, about 30 questions were answered per data segment.

Actual Issue Pre-Interaction
Characteristics of the Actual Issue
SPerceived Issue Pre-Interaction
Characteristics of SPerceived Issue

Characteristics of SPerceived Issue

Does the C component have an element of Uncertainty to it?

Yes

No

<< TOC >>

Survey Completion
0% 100%

Instructional Guide

The SPerceived Issue is the issue students think they have.

Mark "Yes" if this issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Mark "No" if this issue creator seems confident about this component of the issue.

Examples:
(C, CWhy, PWhy) "Um, I think it's because of this, but I'm not sure."
(P) "Um, I think we use this equation, but I'm not sure."

(C, CWhy, PWhy) "F is negative 'cause it's for... graaaaaaavity? I don't know."
(P) "F is negative... maybe? I don't know."

Figure 4.47: A sample survey question as it appears to the coder. The survey section headings are on the far left. The current section title, survey question, and possible responses are in the green box in the middle. Examples are below the box, and question instructions and definitions are on the far right.

The coder uses a transcript of the data segment, as described in Chapter 3, along with the video of the data to take the survey. The transcript includes the AI, SPI, and TAFI components alongside the dialogue. Samples of both transcript and video can be seen in Figure 4.48 and Figure 4.49. The survey is taken once by each coder for each data segment.

Time	TA	Speech			Key:	Actual Issue creator	SPerceived Issue creator	skipped timestamp	interaction period	relevant dialogue	writing irrelevant dialogue
		S1	S2	S3							
1:25:04				how would you find mass of each of the?							
1:25:05											
1:25:06											
1:25:07											
1:25:08				wait							
1:25:09		(pointing) I mean there's the		uhohhh							
1:25:10		(pointing) Rest mass right there									
1:25:11		(pointing) of each of the 2									
1:25:12		(pointing) (undetectable)									
1:25:13											
1:25:14				so would you divided by the speed of light because rest							
1:25:15				Oh wait							
1:25:16				no nevermind							
1:25:17				I don't know							
1:25:18				(laughter)							
1:25:19											
1:25:20											
1:25:21											
1:25:22											
1:25:23		yeah									
1:25:24		that's									
1:25:25											
1:25:26											
1:25:27		(undetectable)									
1:25:28		(undetectable)									
1:25:29		mass									
1:25:30											
1:28:13		but how do we find the m c squared? like the final m c squared since we don't have-									
1:28:14											
1:28:15											
1:28:16				is the rest mass just the plain mass of the?							
1:28:17											
1:28:18		almost									
1:28:19											
1:28:20		is it divided by the sss-									
1:28:21		rest mass									
1:28:22		what's the unit for this mass?									
1:28:23											
1:28:24											
1:28:25											
1:28:26											
1:28:27				I have no idea							
1:28:28											
1:28:29		m c squared um									
1:28:30											
1:28:31		at the end this is in (mouse)									
1:28:32		parantheses (mouse)									
1:28:33		then									
1:28:34		atomic mass units		atomic mass units							

Actual Issue	
C	CWhy
P	PWhy
How to calculate the rest mass	

SPerceived Issue	
C	CWhy
P	PWhy
How to calculate the rest mass	

TAFocused Issue	
C	CWhy
P	PWhy
How to calculate the rest mass via unit analysis	

Figure 4.48: Part of a data segment to be coded using the survey. Transcription from the raw data is on the left while a description of the Issue is on the right.

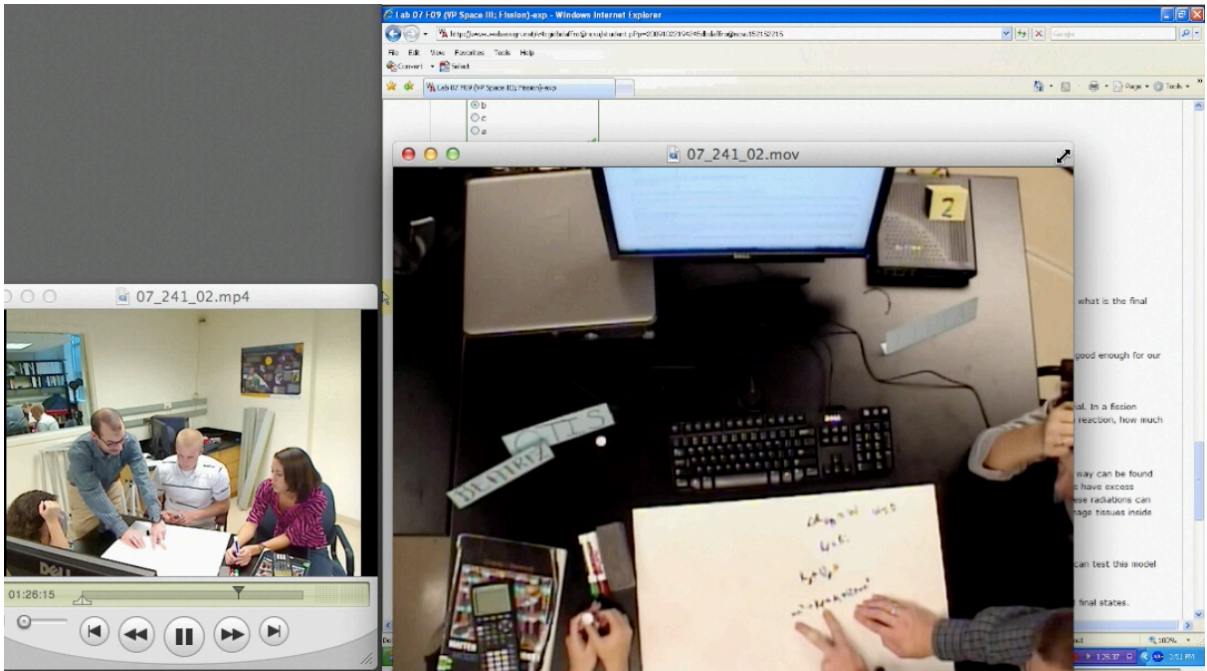


Figure 4.49: A sample scene from the video data used alongside the transcript when coding with the survey.

4.3 Agreement

Once enough of the data was analyzed to solidify the framework features and design the coding tasks, I worked with other researchers to establish inter-rater agreement between coders.⁴⁰ Inter-rater agreement is used to establish reliability of the framework features. Reliability is a way of testing repeatability of the coding instructions and definitions. Additionally, since most of the data is coded by determining the presence of each single feature, this calculation helps establish validity of the features as well. Validation of the codes strengthens the inferences made from the application the codes to the data. Along with the agreement calculation, post-discussion results also helped establish the validity of the framework features. Reliability and validity measure the robustness of the framework.

There are multiple ways to calculate inter-rater agreement (Banerjee, 1999; Krippendorff, 2004). However, the method used to establish inter-rater agreement must meet certain qualifications for this study to mitigate the possibility of misleading agreement results. First, it must account for the possibility that some of the agreement seen might be due to chance. Second, with the survey questions specifically, the method must account for the possibility that one coder may see and answer a question that the second coder did not see or answer in any given round of the survey (missed codes). Third, the method must account for the small sample size of the data. Finally, there is the possibility that some of the features of the framework will be present far more often than absent. This causes a high prevalence of a particular code for those features. Thus, the agreement method should also account for instances of prevalence.

A commonly used agreement calculation in the PER field is Cohen's Kappa (Cohen, 1960). Cohen's Kappa has the benefit of taking into account possible chance agreement between two coders. However, Cohen's Kappa requires too large a sample size to get an accurate measure of agreement.

Instead of Cohen's Kappa, I used Krippendorff's Alpha to calculate agreement (Krippendorff,

⁴⁰There were never more than two coders coding any given task, but the specific researcher changed depending on the task.

2004). Krippendorff's Alpha (α_K) allows for a smaller sample size. The sample size required varies with the coding history. Some of the coding tasks and survey questions will have a large enough sample size to meet the minimum required.⁴¹ The minimum sample size calculation is:

$$N_c = z^2 \frac{(1+\alpha_{min})(3-\alpha_{min})}{4(1-\alpha_{min})p_c(1-p_c)} - \alpha_{min}$$

Where α_{min} is the minimal acceptable α value of agreement, z is the z value for a one tailed test determined by the desired level of confidence, and p_c is the smallest estimated proportion of values c in the population. In most of the coding in this study, $c = 2$ as most of the tasks require binary coding: "feature present" or "feature not present." p_c is based on coding history, making it variable and is calculated separately for each sorting task and survey question, making it unique to each. Thus the sample size N_c is unique to every question and sorting task and can change as additional data segments are coded.

α_K calculates the ratio of observed disagreements to expected disagreements and subtracts that ratio from 1 to get the overall, chance corrected agreement (Krippendorff, 2004, p. 223-232). α_K calculates agreement based only on the number of pairs of codes in each unit coded, not on every individual code. Thus, if only one of two coders saw and answered a particular question, that response would not be counted in the agreement calculation.

α_K takes into account chance agreement in the following way: if code "a" shows up in n_a number of pairs in a given set of data and code "b" shows up in n_b number of pairs in a given set of data, their total number of appearances, n , is given by $n = n_a + n_b$. The chance that any two coders will randomly select different codes (one selects a and the other b) is given by $n_a * n_b / (n - 1)$. This is the chance that those coders will disagree, given this particular dataset. Then the generalized expected disagreement, D_e is given by

$$D_e = \frac{n^2 - \sum_i n_i^2}{n-1}$$

The observed disagreement is given by

⁴¹Even with this method, not all survey questions or sorting tasks will include a large enough sample to check agreement.

$$D_o = n - \sum^i o_{ii}$$

where o_{ii} are the pairs of observed agreed upon codes. Finally, α_K is given by

$$\alpha_K = 1 - \frac{D_o}{D_e} = 1 - (n - 1) \frac{n - \sum^i o_{ii}}{n^2 - \sum^i n_{ii}^2}$$

Krippendorff (2004) recommends acceptance of codes that establish a α_K of .800 or higher and rejection of codes that establish a α_K of less than .667.

Alpha Statistic	Agreement Strength
> .80	Excellent
.667 – .80	Moderate
< .667	Poor

Finally, Krippendorff's alpha does not account for prevalence. To that end, simple agreement will be added in as a check for prevalence. Simple agreement is the total number of codes agreed upon in a given category or question divided by the total number of segments coded.

$$\text{Simple Agreement} = \frac{\# \text{ of agreed upon segments}}{\text{Total } \# \text{ of coded segments}}$$

It does not give the most robust measure of reliability because it does not take into account chance agreements. But it can be used to get a surface level measure of agreement and as a check for problems with prevalence. Prevalence can be seen in instances in which simple agreement is high, but α_K is low.

α_K and simple agreement are used to test reliability of all individual survey questions, Issue Content Categories sorting tasks, and Characteristics of the Interaction sorting tasks. Simple agreement alone is used to test the reliability of the survey as a whole (all coded survey questions together) and the validity of the Issue components.

A final note on the limitations of reliability calculations

Ideally, inter-rater agreement would be done on a sample of data similar, but not identical, to that used in the study (Krippendorff, 2004, p. 217). This sample would be used to train a second coder and refine definitions and instructions. Agreement would be calculated on this sample, and then the second coder would code 10% of the research data. The goal would be to reach a α_K of at least .8 with 95% confidence by coding 10% of the data.

This was not possible in this study. When all data collection and processing was complete, I had a sample size of 50 data segments to work with (later reduced to 47 segments). Due to the nature of the various coding tasks, some tasks would not even use all 50 samples.⁴² I chose to proceed with the inter-rater agreement process with these 50 data segments regardless, and to use them to refine the definitions and instructions for coding.

4.3.1 Agreement Results

Using the above methods, I tested the reliability and validity of the framework. Below I break-down the results of these tests, summarize the conclusions from them, and discuss disagreements. A detailed table of all results can be found in Appendix C. I will cover the four agreement tasks and results in the following order:

1. Issue Components (2 matching tasks)
2. Issue Content Categories (3 sorting tasks)
3. Characteristics of the Interaction (6 sorting tasks)
4. Issue Coding Survey

Agreement Task 1: Issue Components

I described a process for identifying the Issue components in the beginning of Section 4.1.1. In an initial attempt to validate the Issue components, I met with two other independent

⁴²Due to differences in data segmentation for the Characteristics of the Interaction Sorting Tasks, these tasks included slightly more than 50 data segments.

researchers and reviewed the process I used to identify the Issue components. Then, we discussed an example transcript that showed the Issue components for that data segment. Discussions of this example focused on identifying *what* the Issue was over *why* it occurred. By our third and final meeting, the researchers took on the process of identifying the Issue components on their own and identified the same Issue components I had identified. This process was generally successful. However, not wanting to monopolize other researchers' time, I decided it was not worth continuing the process for the rest of the data. This leaves the specific Issue components unvalidated.

The general Issue (all the components together) was validated using two matching tasks. First, I combined all the AIs and the TAFIs together to create 73 unique Issues.⁴³ I randomized their order using a random number generator. Second, I isolated the transcripts within each data segment so that there were two unique sets of transcripts. The first contained only the students' dialogue and actions before the interaction began in each data segment. The second set contained only the dialogue of the students and the GTA during the interaction. These were also separately randomized. There were 50 of each.

Third, a researcher took the set of 50 "during the interaction" transcripts and attempted to match each one to its respective TAFI. Fourth, a different researcher did the same task but with the 50 "before the interaction" transcripts, attempting to match each one to its respective AI. Different researchers did each sorting task to avoid biasing the results. I will divide the results by each task. Instructions for each task can be found in Appendix B.

Matching the TAFIs

The second researcher initially matched 74% of the Issues to their respective transcripts. Upon clearing up disagreements due to unclear content in the transcript⁴⁴ the agreement rose to 82%. Further disagreements stemmed from the complexity of the data and were otherwise non-

⁴³Since some Issues were worded identically, there was an uneven number of Issues as well as a smaller number of unique Issues than the size of the data sample.

⁴⁴My initial transcription was rough and sometimes I missed places that needed more context.

descript. We reached 100% post-discussion agreement. This level of agreement establishes a measure of validity of the TAFI descriptions.

Matching the AIs

In the first attempt at this task, the second researcher matched 60% of the Issues with their respective transcripts. After meeting and discussing the first 10 segments, it became clear that I needed to refine the task instructions. After doing so, our pre-discussion agreement rose to 78%. After clearing up trivial disagreements due to unclear content in the transcript the agreement rose to 83%. We agreed on all of these after discussion and reached 100% post-discussion agreement. This level of agreement establishes a measure of validity of the AI descriptions.

Our disagreements stemmed from slight differences in wording between the Issues and the transcript. One specific disagreement arose when the second researcher chose an Issue that was far more detailed than the transcript provided. This led to a final rule (to be tested in future validations) that Issues will not match with transcripts when the Issue holds more detail than the transcript. Issues can match when they hold less detail than the transcript. This ensures that researchers will not make more than the necessary assumptions when identifying an Issue and helps regulate biased decisions.

Matching the SPI

No matching task was done to validate the SPI as the SPI served as a placeholder in this study. I did not use it other than to note its existence or lack thereof, and so did not need to validate its contents. However, as Section 5.7 shows, I now think the SPI should be validated in future research.

Issue Creators

While I set up guidelines for determining which students created an Issue, the purpose of this determination was to appropriately focus the features of the framework. Identification of the

Table 4.2: Issue Content Category Reliability Results. Bold under “Sample Size N” columns indicates necessary sample size was exceeded in this study. Bold under “Reliability Results” columns indicates $\alpha_K \geq 0.667$ or Simple Agreement ≥ 0.8 for adequate sample size.

Issue Content Category Reliability Results

Sorting Task	Reliability Results			Sample Size N required for various combinations of α_K s and confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Con vs. Ex	44	0.64	0.84	52.25	31.88	30.29	18.48
GS vs. SA	30	0.89	0.97	61.62	37.60	35.82	21.86
UC vs. O	13	1.00	1.00	51.42	31.37	29.80	18.18

Issue creator provided a perspective from which to view the Issue and the students’ process. I do not draw any conclusions based specifically on Issue creators. Thus, no agreement was done on determining the specific Issue creators. If one were interested in further studying the Issue creators specifically, one could use a matching task to assess agreement on them.

Agreement Task 2: Issue Content Categories

To determine which content categories the Issues belong in, I used a sorting task that involved three sorts of the data using randomized data segment transcripts. I used only the dialogue from before the interaction for this task. I initially conducted this task with a second researcher to refine instructions and category definitions. No agreement was calculated from that task. I then completed the three sorts with a third researcher. I calculated the necessary sample sizes, simple agreement, and our α_K agreement. The results can be seen in Table 4.2.

There were 44 data segments in the first sort on Construction vs Execution.⁴⁵ This allowed me to accept an alpha of .8 with 90% confidence and an alpha of .667 with 95% confidence. This sort gave a simple agreement of 84% and a α_K of .64 prior to discussion. After discussion, we reached a simple agreement of 100% and a α_K of 1. Future work on this sort should include continuing to refine the category definitions and repeating the agreement task to attempt to reach higher agreement. Coding discussions and post-discussion agreement helped establish some measure of validity of these categories.

Most legitimate disagreements arise due to complexities in the data. When I discuss disagreements of this and the remaining tasks, I acknowledge that, at the most basic level, these disagreements have come from the difficulty of coding this data. I seek then to explain the disagreements at a more practical level that may be useful to future researchers.

In this particular sort, disagreements arose from three places, missed rules, assumed context, and data complexity. Missed rules accounted for 25% of disagreements, and were quickly corrected.

50% of disagreements were due to assumed context. Instructions were given that the coder should assume all context is contained within the data segment transcript. Disagreements disappeared after this rule was initiated.

Complexity in the data made up the remaining 25% of the disagreements. One noteworthy disagreement occurred over students creating an Issue when selecting a value for a quantity in their solution. In this instance, students discussed physics concepts supporting their move. The value selection would indicate a coding of Execution, while the discussion of physics concepts warranted a code of Construction. We decided here to err on the side of the more sophisticated piece of what the students were doing. Thus a rule was added that value selections including discussion of physics concepts are to be coded as Construction.

There were only 30 data segments for the second sort on Getting Started vs Solution Approach. This allowed me to accept an alpha of .667 with 90% confidence. This sort gave a

⁴⁵I removed the six No Issue segments from this agreement task.

simple agreement of 97% and a α_K of .89 prior to discussion. Only one trivial disagreement arose and was immediately corrected leading to a simple agreement of 100% and a α_K of 1. Coding discussions and post-discussion agreement helped establish some measure of validity of these categories.

The final sorting of Unit Conversions vs Other was the smallest sample size yet, 13 data segments. With a sample this small, I can not accept any conclusions drawn.

Agreement Task 3: Characteristics of the Interaction

Sorting tasks were also used to check agreement of the interaction characteristics features. I initially conducted these tasks with a second researcher to refine instructions and category definitions. No agreement was calculated from that task. I then conducted the tasks with a third researcher. The same researcher was used for the survey and for 5 of the 6 sorting tasks in this section.⁴⁶ The following Table C.3 shows the necessary sample sizes, simple agreement, and α_K agreement for all 6 sorting tasks.

⁴⁶This researcher was not able to be present for the Diagnosis sorting task. A different researcher conducted that task. The researcher who conducted the Diagnosis sorting task was not previously familiar with the data but was familiar with the labs from which the data was taken.

Table 4.3: Characteristics of the Interaction Reliability Results. The “*” denotes α_K values that may be lower than expected due to prevalence. Bold under “Sample Size N” columns indicates necessary sample size was exceeded in this study. Bold under “Reliability Results” columns indicates $\alpha_K \geq 0.667$ or Simple Agreement ≥ 0.8 for adequate sample size.

Characteristics of the Interaction Reliability Results

Sorting Task	Reliability Results			Sample Size N required for various combinations of α_K s and Confidence Levels (CL)			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Diagnosis	53	0.55	0.68	65.21	39.79	37.93	23.15
Who Directed	52	0.73*	0.92	63.3	38.62	36.81	22.46
How Students Directed	9	0.52	0.67	58.11	35.46	33.75	20.59
How TA Directed	44	0.77	0.89	51.42	31.38	29.8	18.19
Do Students Share Ideas	54	0.68*	0.91	62.87	38.37	36.56	22.31
How Do Students Share Ideas	9	0.15	0.56	51.49	31.42	29.84	18.21

Diagnosis

The Diagnosis sort involved sorting the data into four categories based on how the GTA came to focus on the TAFI: Active, Listen, Work, Abbreviated. The sample size was large enough to allow me to accept an alpha of .8 with 90% confidence and an alpha of .667 with 95% confidence. This sort gave a simple agreement of 68% and a α_K of .55 prior to discussion. After discussion, we reached a simple agreement of 100% and a α_K of 1. Coding discussions and post-discussion agreement helped establish some measure of validity of the Diagnosis feature.

This sorting task was done without proper coder training since I did not have a large enough sample size to familiarize the coder with all categories and rules. Thus, 75% of all disagreements stemmed from the coder getting familiar with the coding instructions and definitions.

Complexities in the data accounted for the remaining 25% of disagreements. Complexity in this sort centered around how to interpret the data and included things like deciding whether the GTA was actually responding to student's questions or to their work, and in another case whether the GTA question was in fact probing. These segments were agreed upon after discussion with the decision that no additional rules need be added or modified.

Who Directed, How Directed, and Students Sharing Ideas

These three sorting tasks had very similar agreement results, so I summarize them together here: The Who Directed (GTA or Students), How TA Directed (with or without students' input), and Students Sharing (whether or not students shared ideas). The sample size for each of these tasks was large enough to allow me to accept an alpha of .8 with 90% confidence and an alpha of .667 with 95% confidence. The Who Directed sort gave a simple agreement of 92% and a α_K of .73 prior to discussion. The How TA Directed sort gave a simple agreement of 89% and a α_K of .77 prior to discussion. The Students Sharing sort gave a simple agreement of 91% and a α_K of .68 before discussion. After discussion, we reached a simple agreement of 100% and a α_K of 1 on all three tasks. Coding discussions and post-discussion agreement helped establish some measure of validity of these framework features.

Although the α_K s for Who Directed and Students Sharing Ideas are in an acceptable range, they are lower than expected for the high simple agreement seen. One possible reason for this is the overwhelming presence of one code over another in these sorts. This is the problem of prevalence I mentioned earlier. In the Who Directed sort, we initially agreed upon the GTA directing the conversation in 41 of 52 segments (79%). This indicates there is prevalence of the TA Directs code in this data. In the sort determining whether or not students shared ideas, there is also a prevalence of the code Not Sharing Ideas. Students do not share ideas in 42 of 54 data segments (78%).

Similar to the Diagnosis sorting task, 50% of disagreements in the Who Directed and Students Sharing Ideas sorting tasks arose due to the sample size limitations that prevented sufficient coder training. The remaining disagreements were due to data complexity.

In the sort for How the GTA Directed the interaction, all disagreements arose from misinterpretations of the GTA's pauses in the transcript. These were cleared up by watching the video along with following the transcript. It is advised that all future codings be accompanied by watching video.

The two sorts of How Students Directed and How Students Shared carried samples sizes too low to accept any conclusions drawn.

Agreement Task 4: Issue Coding Survey

A second researcher coded 49 data segments using the survey. The coder was trained on four data segments prior to coding the 49 segments. While these four segments were helpful in getting used to the survey, coding definitions, and data, they did not cover every question asked in the survey, nor did they allow for enough discussion to mend any patterns of disagreement. Thus, the 49 data segments also served as the way to continuously refine questions and definitions as well as create rules regarding particular observations in the data. Complete agreement tables for the survey can be found in Appendix C.

Agreement of the overall survey was found by taking a simple agreement calculation of all questions answered by both the second researcher and myself over all data segments. The resultant agreement is 81% prior to discussion, and 100% after discussion.⁴⁷ I found simple agreement to be the best measure of agreement for the overall survey.

The survey had 146 possible questions requiring agreement calculations.⁴⁸ Of the 146 questions, 106 were answered at least once by both the second coder and myself. The remaining 40 questions were largely added for completion of the framework, even though they were not specifically represented in this sample of data. When I break down the agreement results, then, I am talking about these 106 questions. I can further break this down since 85 questions that *were* answered, were not answered enough times to meet minimum sample size requirements for agreement. This leaves 21 questions for which the sample size was large enough to check agreement at a minimum α_K of .667 with 90% confidence. Table 4.4 shows the per question breakdown of sample sizes, α_K , and simple agreements for these 21 questions. A table showing all agreement results and sample sizes can be found in Appendix C.

⁴⁷Discussions concerned each individual question as we coded the data segments. There was no discussion concerning the overall survey.

⁴⁸Several other questions involved following instructions, and so are not included here.

Table 4.4: Issue Coding Survey Reliability Results. Bold under “Sample Size N” columns indicates necessary sample size was exceeded in this study. Bold under “Reliability Results” columns indicates $\alpha_K \geq 0.667$ or Simple Agreement ≥ 0.8 for adequate sample size. The “*” denotes α_K values that may be lower than expected due to prevalence.

Issue Coding Survey Reliability Results

Sorting Task	Reliability Results			Sample Size N required for various combinations of α_K s and confidence levels(CL)			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Q2.5	42	0.60	0.81	51.57	31.47	29.89	18.24
Q2.11	42	0.66*	0.90	64.60	39.42	37.58	22.93
Q2.12	40	0.75	0.88	51.43	31.38	29.81	18.19
Q3.1(P)	37	0.46	0.73	51.42	31.37	29.80	18.18
Q3.2(P)	37	0.51*	0.81	54.10	33.01	31.38	19.15
Q5.1(P)	29	0.45*	0.83	60.16	36.71	34.96	21.33
Q5.2(P)	29	0.07*	0.66	54.94	33.53	31.88	19.45
Q5.3(P)	29	0.35*	0.83	64.71	39.49	37.64	22.97
Q7.2(P)	37	0.28*	0.89	102.62	62.62	60.00	36.61
Q7.3(P)	32	0.82	0.94	57.38	35.01	33.31	20.33
Q7.5(P)	31	0.46*	0.81	56.74	34.62	32.94	20.10
Q11.2_(get it)	28	-0.33	0.32	51.41	31.37	29.80	18.18
Q11.2_(rectify)	27	0.28*	0.78	61.41	37.47	35.69	21.78
Q11.2_(redirect)	27	0.14*	0.78	68.32	41.69	39.77	24.27
Q11.3	28	0.52*	0.86	62.12	37.91	36.12	22.04
Q12.1	42	0.73	0.81	62.2	37.95	36.16	22.06
Q13.3	42	0.73*	0.93	67.13	40.96	39.07	23.84
Q18.2	41	0.12*	0.80	107.28	65.46	62.75	38.29
Q18.3	42	0.25	0.62	51.41	31.37	29.80	18.18
Q18.4	42	-0.04	0.69	60.77	37.08	35.31	21.55
Q18.5	40	0.63	0.93	80.59	49.18	47.01	28.68

Coding discussions and post-discussion agreement help establish some measure of validity of the framework features. Post-discussion simple agreement was 100% with a α_K of 1 on all questions. No question got enough responses to meet the minimum sample size at which I could accept α_K of .8 with 95% confidence. Knowing the sample is small, I recommend future research continues establishing inter-rater agreement of all questions. Finally, I draw attention to the simple agreements in Table 4.4 as many of them are above 80%, even with low α_K . When a low α_K is accompanied by a higher simple agreement, there is most likely prevalence of one code affecting the α_K value. This is noted in the table with an “*.”

The coding process began with each coder taking the survey for a single data segment. Disagreements were discussed, and then the coders took the survey again with the next data segment. This process ended once all data segments were coded. Since each coder had to focus on all survey questions that appeared per segment, the coders did not have a chance to familiarize themselves with one particular question across all data segments without the distraction of the other questions. This division of focus, required to fully code each data segment, accounts for some of the disagreements that arose on individual questions. This can be seen in disagreements in which coders mixed up responses to similar survey questions.

In light of this, I do not think the method of completing the survey in its entirety for each data segment and then moving on to the next one is the most appropriate method for checking reliability of the individual questions. I recommend future agreement tasks separate the survey into its individual questions and consider each question a sorting task as was done in the previous sections. A larger sample of data is also recommended because, as mentioned above, coding by sorting task was still difficult with the small sample size.

As mentioned above, the main goal with testing agreement of the survey was to continue the process of refining the instructions for each question and thus refining the behaviors represented by the features. Thus, the disagreements we had often led to minor rules about specific behaviors in the data. All minor rule additions can be seen in the full set of survey questions and instructions in Appendix C.

4.3.2 Summary of Agreement

I summarize the agreement here to clarify what conclusions can be accepted and how strongly. As is shown in the discussion above, the framework is not very robust yet. Many of the sample sizes are too small to test reliability and validity of a code. Future research should repeat agreement with a sample size large enough to allow me to accept an alpha of .8 with 95% confidence. Also, many of the α_K s are too low to accept any conclusions from my results. However, the presence of higher simple agreement in many cases and the fact that all post-discussion agreement is 100% shows that the framework does have potential to become more robust with larger sample sizes and refining of the coding instructions and definitions. Additionally, the discussions on coding and post-discussion agreement established some measure of validity of the framework features.

To understand the potential value of the framework as a tool for analyzing students' and student-GTA interactions, I present the results and conclusions as if the framework is already robust. However, only certain conclusions can be accepted. I review the features that can be accepted or tentatively accepted in Table 4.5. I will return to this table in Chapter 6 when I present my conclusions to this study.

Table 4.5: Framework features with acceptable α_K values.

Framework Features Agreement Summary

Coding Tasks	Framework Features	α_K
Issue Content Category	Getting Started vs Solution Approach	$\alpha_K: 0.89$
Characterisitics of the Interaction	Who Directed	$\alpha_K: 0.73$
	How TA Directed	$\alpha_K: 0.77$
	Do Students Share Ideas	$\alpha_K: 0.68$
Issue Coding Survey	Inquiry Question - Qi (Survey Question 2.12)	$\alpha_K: 0.75$
	Conceptual for AI-P - Conc (Survey Question 7.3(P))	$\alpha_K: 0.82$
	Issues Beginning the Interaction - I-Start (Survey Question 12.1)	$\alpha_K: 0.73$
	Move Forward During the Interaction - Move (Survey Question 13.3)	$\alpha_K: 0.73$

Chapter 5

Results

In this chapter, I examine the results of applying the framework across the data segments. I identify the common features connecting the interaction to what the students do before, during, and after the interaction to answer my research questions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

I then reflect on these features and their significance to GTAs' interactions with students and students' processes.

I first discuss the features that trend through the entire dataset. A complete table of features and descriptions can be found at the end of Appendix B. In so doing, I relay the most common story revealed by these features across the data and call this the "Typical Story." I then split the Issues into their respective content categories (reviewed below in Section 5.1) and further explore trends in each category (Getting Started, Solution Approach, Conversions, Other, No Issue). Within each category, I'll pull out the common features and relay the most typical story of an Issue within that category. I will review examples from my data to illustrate what

these stories look like. I'll then discuss atypical cases of interest in comparison to the typical story. I examine a few framework features as they change across categories and across GTAs. A complete table of results by content category and by GTA can be found in Appendix D. Finally, I discuss limitations of the framework.

Before beginning, I note that my study produces results and describes findings in a different form from previous studies on GTA-student interactions. For instance, the Issues Framework is designed to tell a descriptive story of the students' process and how the interaction fits into and influences that process. This is different from previous literature on GTA-student interactions that often focuses more explicitly on the range of observed GTA behaviors. Therefore, except where appropriate, I generally refrain from making explicit comparisons of my findings to previous studies on GTA-student interactions.

5.1 Typical Story - All Data Together

In this section, I identify the features common to all the data segments and the story those features tell. When I talk about finding typical stories and features for all the data, I am simply referring to those that occur most often. I have 47 data segments, and I define "most often" as occurring in 65% of them. 65% was chosen because it was the most stringent proportion that still revealed a complete temporal story - pertinent features before, during, and after an interaction - across the entire dataset and within each Issue content category. I also include daughter features¹ that occur in more than 50% of the total data segments in which the parent feature occurs in at least 65% of the total.

In this examination, certain features that might occur more frequently under a parent feature are missed because that parent feature is not present often enough. For instance, in all Issues created Thoughtfully, most are also created using Collaboration. However, less than 65% of the Issues are created Thoughtfully. So the common diagram does not highlight Collaboration. This

¹Daughter features are those that can only appear if a bigger, parent feature also appears. For instance, AI - P's Error can only appear if AI - P appears. Thus, Error is a daughter feature.

dural component.² This shows that most of students' Issues involve making some procedural move during problem solving. The physics content they discuss is centered around making these procedural moves, and often these moves have Errors. This is not really surprising. The physics problem itself is asking students to do something, and so most Issues are created around attempting to do those things. The students' focus is on getting through the problem, and procedure is the main requirement for that. However, having many Issues with only a Procedural component means that the reasoning or conceptual ideas backing these moves is not expressed (PWhy, C, and CWhy components). Thus, there is a lack of physics content expressed. Note, I am not inferring that no reasons or conceptual ideas exist behind students' moves, only that these reasons are hidden.

Looking at the common features during the interactions shows that the Procedural component is usually Addressed with Procedural talk and Resolved.³ This tells me that, during the interaction, the students are influenced to change the inappropriate procedural moves they made before the interaction, to appropriate moves. This signifies a change in their process.

The GTA focuses on the same component as that of the students' Issue, though the TAFI - P does not always match the AI - P (thus the split colors). Two features highlight the characteristics of the interactions - SiStart and TAdirect. Most Issues are brought up in interactions that are begun by students⁴ but directed by the GTA. After the interaction, the students Move forward, indicating the interaction has allowed students to progress forward with the problem. Finally, I note that half of all Issues occur in the Solution Approach category, while the remaining Issues are distributed more evenly among the other categories.

The general story shows that the students ask the GTA about some procedural move in which they have made an Error, and the GTA helps direct them to doing it correctly. By the time the GTA leaves, the students know how to do the move correctly, and they can Move forward to the next piece of their solution after the interaction. If anything, this common story

²I can't specify the procedural moves within this component, as the content of each AI - P component is unique to its data segment.

³A complete table of Issues Framework features and descriptions can be found at the end of Appendix B

⁴This differs from Scherr et al. (2006) in which the GTAs began most interactions.

paints a fairly generic picture of students focused on making procedural moves and GTA's focused on correcting the moves.

A main goal of this study is to identify how the GTA-student interaction is situated in the students' processes. In this common story, the students' process is primarily Procedural (AI - P), and students are creating Errors in their procedure. Their processes change during the interaction to reflect a correction to their procedure (Resolution). After the interaction, their process shows them continuing to solve the problem (Move), leaving their procedural Issue behind. The interaction is situated in this process so as to focus narrowly on a procedural Issue (TAFI - P, Address, Procedural talk) with emphasis on the GTA Directing students to correct their Error (Resolution).

A few features of the diagram stand out due to their absence or an unexpected difference. The first is the coloring of the TAFI. I would expect the TAFI to be the same as the AI, since the GTA is helping students with their Issue. But in fact, the TAFI is different from the AI in at least one component in close to half the data. This is certainly not a majority, but the presence of this mismatch alone is cause for further examination. The second is the lack of GTAs' encouragement of student input (Sinput) and students sharing ideas (Sshare). These features would indicate a GTA who is making an effort to more actively engage students in the interaction. The absence of these features indicates that the GTAs in this study interacted with their students more often through directions and explanations than questions and open conversation.

Finally, one-fourth of the data have AIs with other components included with the AI - P component. Students are expressing their reasoning to each other in fewer Issues than I'd originally expected. Looking at the TAFI, one-third of the data segments have TAFIs with other components alongside the TAFI - P component. Their uncommon appearance suggests an often narrow focus on procedure, rather than a broader focus on the physical situation surrounding the procedure. Also, these other components appear most often in the Solution Approach content category. I will discuss their presence and absence further as I examine each

category.

When I look at the features that do not occur in the typical story of the entire dataset, I see a need to examine the diagrams differently. The framework diagrams allow one to easily identify the complexity of an Issue. The range of complexity of the Actual Issues can be seen by comparing the two example diagrams from the dataset in Figure 5.2 and Figure 5.3.

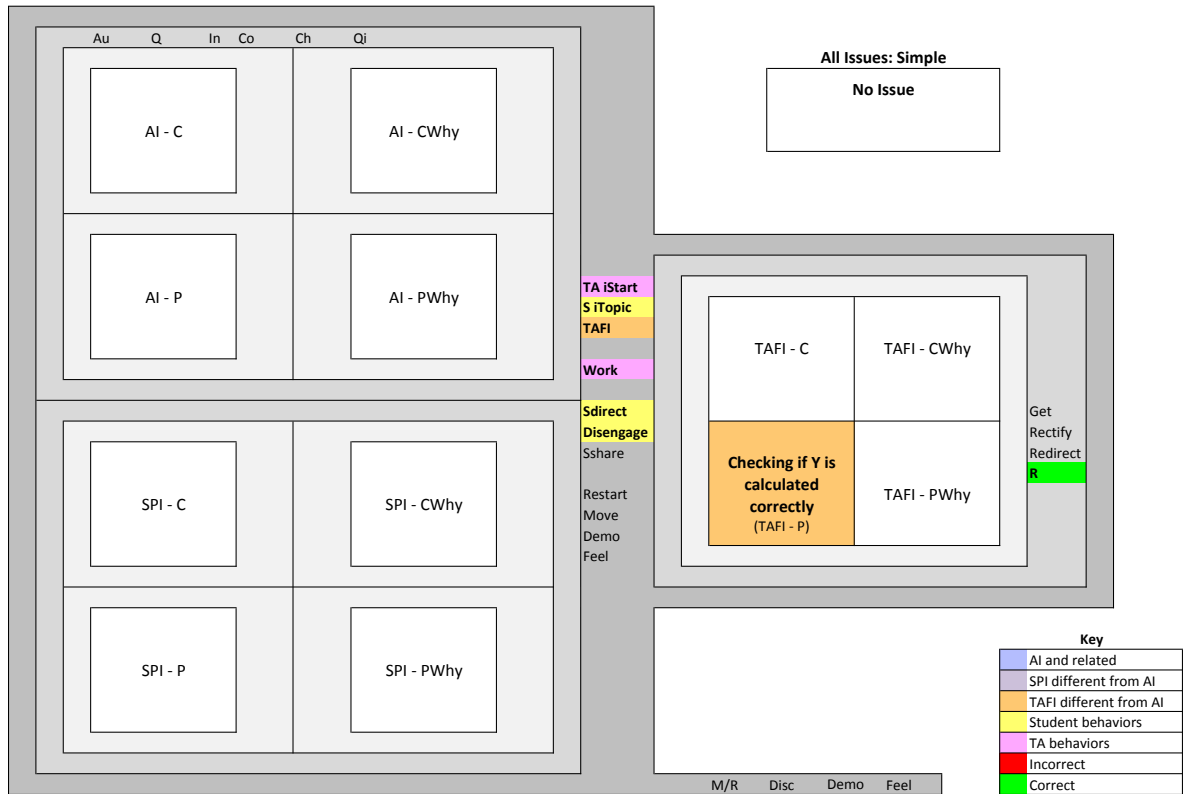


Figure 5.2: A simple Issue diagram from the No Issue content category. It is considered simple due to its scarcity of features.

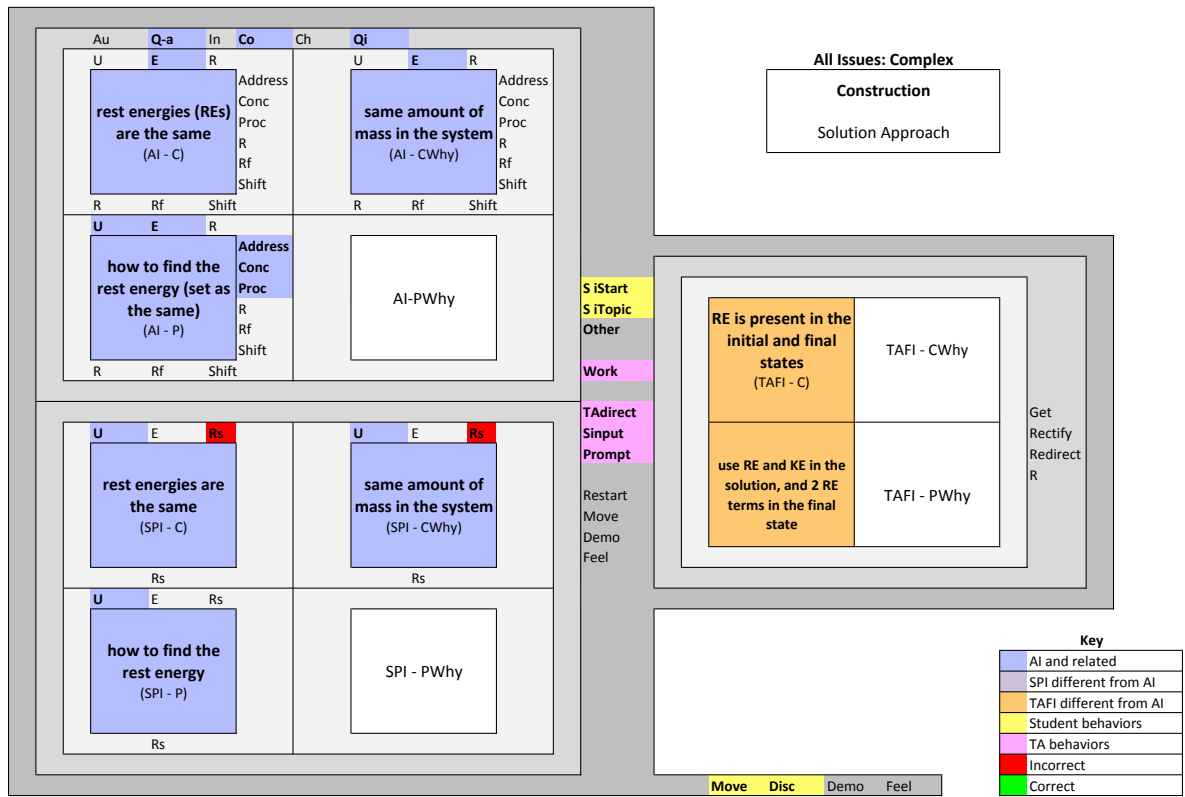


Figure 5.3: A complex Issues diagram from the Solution Approach content category. It is considered complex due to its greater number of features.

This range provides further motivation that grouping the Issues might provide more insight into the interaction and students' processes. Grouping the data by content categories provides a common point to divide from that is not dependent on the framework itself. Thus, I can see what the framework reveals in each category. The sequential nature of the content categories groups the Issues according to a few general problem solving steps. This makes the results more accessible to future researchers and instructors.

In some categories, the typical story I pull out may also tell a fairly complete story of the Issues in that category. In these categories, most of the features missing from the typical story are in fact missing from most of the Issues in that category. In others I reveal a basic outline as I did above, and the discussion becomes more complex. I will identify these different

representations within each category. I briefly review the content categories before discussing the results further:

- Construction - Students are in the process of interpreting the problem and crafting their solution.
 - Getting Started (6 of 47 Issues) - Students are Uncertain how to begin interpreting a problem statement or constructing a solution
 - Solution Approach (23 of 47 Issues) - Students have begun constructing their solution, but create Issues with specific structural pieces of that solution
- Execution - Students have constructed their solution and are working through the finer details of solving it.
 - Conversions (8 of 47 Issues) - Students create Issues around converting (or more often not converting) quantities into appropriate units.
 - Other (5 of 47 Issues) - Students create Issues with the details of the calculations within their solutions. This includes Issues surrounding calculations, non-physics specific formulas (e.g. Area), organizing answers, etc.
- No Issue (5 of 47 Issues) - Students do not create an Issue before an interaction. However the GTA brings up a topic as a possible current or future Issue during the interaction.

5.2 Construction Issues

The first kinds of Issues students create have to do with constructing a solution. These Issues include how to begin to solve a problem, which equations to use, and how to set them up properly, as well as what is going on physically with the problem. These Issues fall into two subsequent categories: Getting Started and Solution Approach.

5.2.1 Getting Started (6 Issues): The Typical Story

Moving temporally through a problem, the first place students create Issues is getting started on the problem. Understanding what a problem is saying and asking can be difficult. And even after understanding what is being asked, how to begin to approach constructing a solution may be challenging. In some cases, then, an interaction with the GTA occurs that is intended to help students over the hump of getting started. While each of the Getting Started Issues is unique, a common story emerges from examining the framework. In this category, I pull out features that occur in at least four of the six Issues to tell the typical story.

In Getting Started Issues, students read through the problem statement and question and find themselves confused by how to begin to answer the question. They may re-read the question, check through notes and/or the book, and even make some attempt at proposing an idea for how to begin to answer the question. However, they do not get so far as to actually begin working on any of those ideas. Instead, an interaction with the GTA occurs to help them get started. During the interaction, the GTA listens briefly to the students' confusion and then helps them over the hurdle of getting started. In order to do this, the GTA often builds a procedure for the students to follow. Students are then able to begin constructing a solution after the interaction. Figure 5.4 shows this storyline in the framework. I will examine this story further by separating it into temporal sections - pre-interaction creation, during, and post-interaction - and examining those individually.

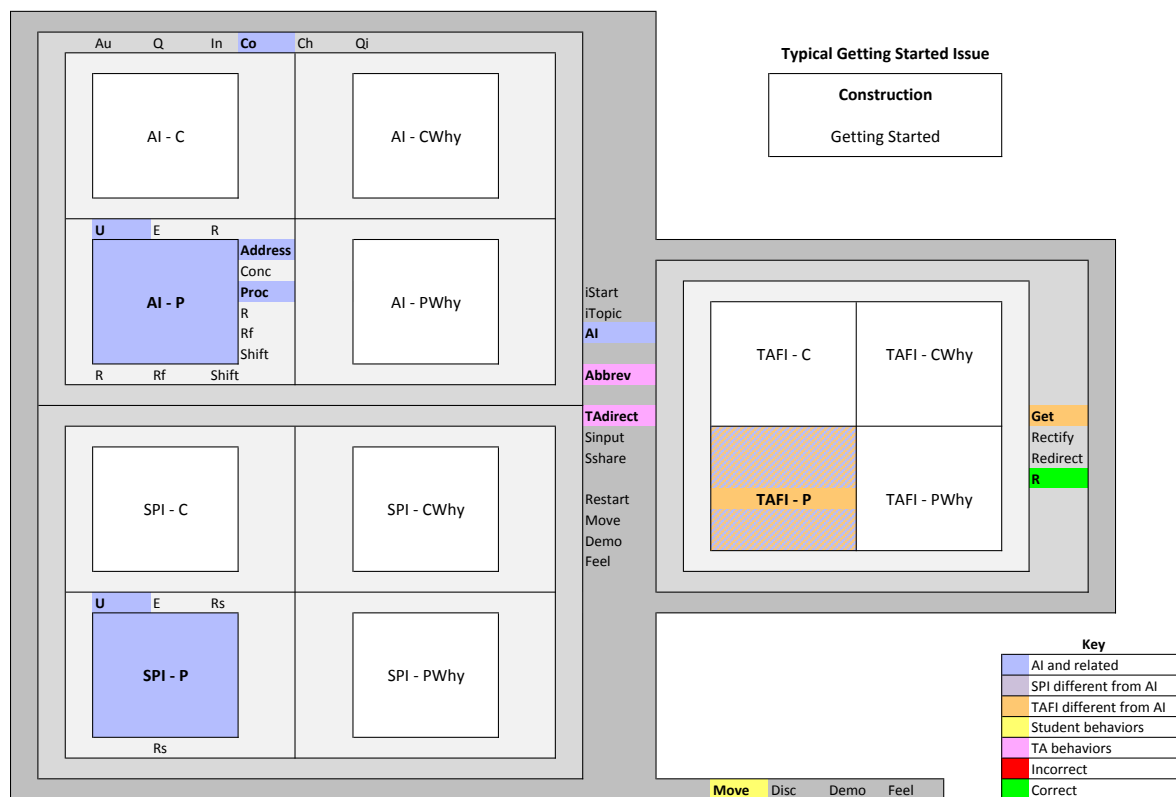


Figure 5.4: The Issue diagram for a typical Getting Started Issue. Features that are present in at least four of six Issues are highlighted.

Pre-Interaction Creation of the Issues

Students create an Issue with the Procedural component only (AI - P).⁵ They do not make a move toward solving the problem, but remain Uncertain about what move to make. They tend to create the Issue Thoughtfully though, aware they are confused (SPI - P - Uncertainty) and Collaborating in their Uncertainty as to what to do. Figure 5.5 shows the diagram highlighting the creation of the typical Getting Started Issue. I review this with the following example.

The example is taken from a group attempting to begin the problem of finding the ΔE of two adjacent energy levels in a nitrogen molecule. The full framework diagram can be seen in Figure 5.6, and the full problem statement and answer cell can be found in Figure 5.7.

⁵In one Issue, students initially admit to not understanding the problem statement, creating an Issue in the Conceptual component.

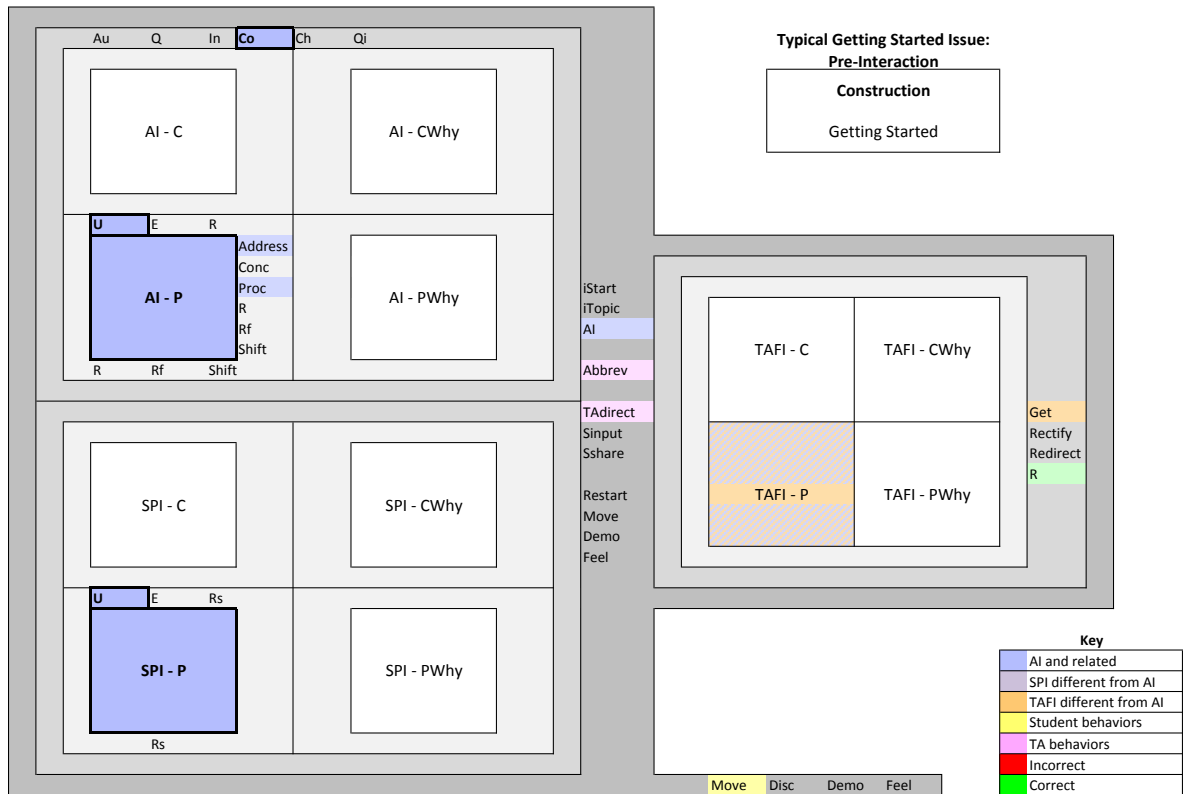


Figure 5.5: The Issue diagram for a typical Getting Started Issue. Highlighted, bolded features are those present before the interaction begins. Other common features are muted.

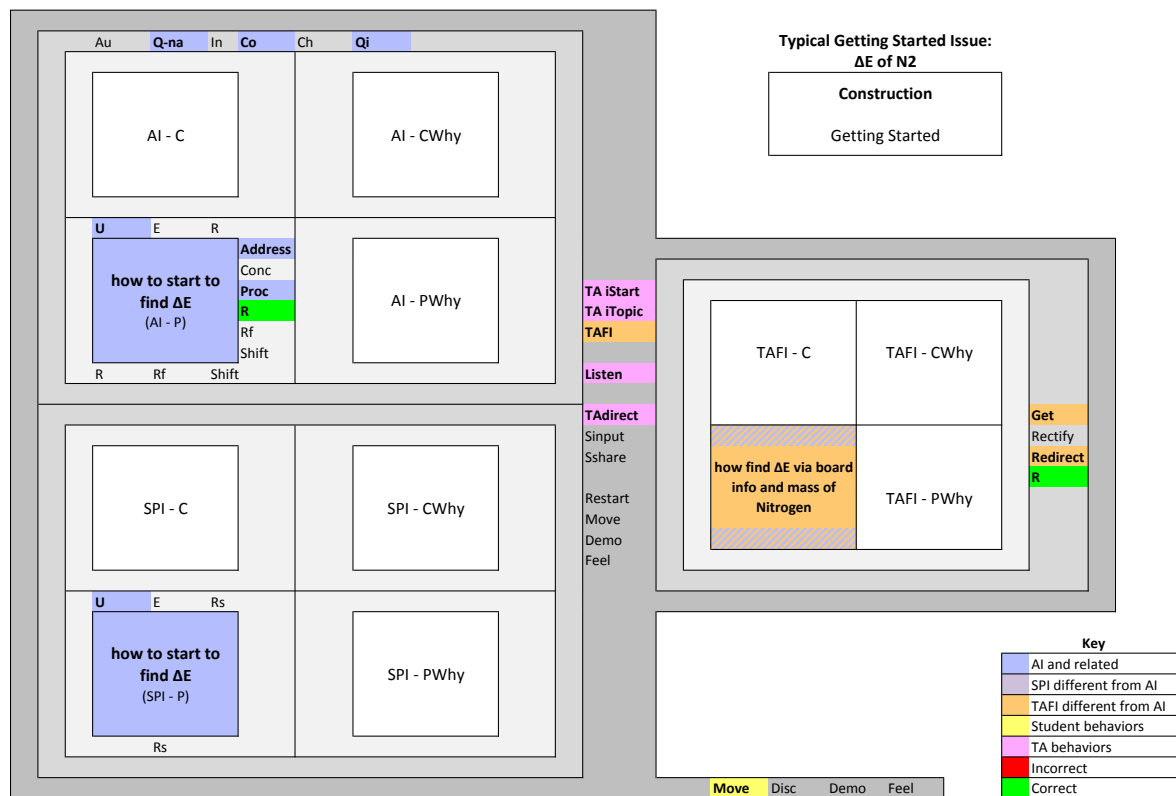


Figure 5.6: An example Issue diagram showing a typical Getting Started Issue from the Spectra Lab Problem 2. This diagram contains all features present in the typical story as well as features unique to the example. All features present are highlighted.

Spectra Problem 2

A diatomic molecule such as N₂ can be considered to be a quantized harmonic oscillator, with quantized vibrational energy levels which are evenly spaced.

Estimate the difference in energy between two adjacent vibrational energy levels for a nitrogen molecule. Some of the information you need to do this can be looked up in your book, but you will have to estimate at least one quantity, based on similar quantities you previously calculated. A range of estimates is accepted here:

$\Delta E \approx$ eV

Figure 5.7: The problem statement for Problem 2 of the Spectra lab.

The students have read the problem and attempt to use some information from the front whiteboard to understand what to do. As in Chapter 4, I color the Actual Issue creator's "name" red for easy identification in this and all following examples. In this first example, there are multiple Issue creators, so multiple names will be colored.

193 **S1:** How do we get this? Um... j-jump energy.

194 **S3:** Nitrogen

195 **S3:** How are we supposed to have an idea? Can you read what's on the board (front
196 whiteboard)?

197 **S1:** I guess, basing off this (looking at previous problem on PC)... So we have to estimate
198 one of the quantities. Change in E iiiis... the... I guess you're not like, adding up all the
199 types of energy? Right? Like vibrational, thermal, all that. (Reads on the PC Screen). Okay
200 so that's what we're asking. I have no idea what to do to estimate this.

201 **S3:** Yeah. I don't know where to start.

202 **S1:** So we're doing one half, mass...

203 **S3:** Problem two. N plus, one half...

204 **S1:** Um, wait. So we have to do the... Is that problem-

205 **S3:** I mean we know the mass of one nitrogen.

206 **S1:** th-that's not even problem two. I'm on problem four, not two.

207 **S3:** Well, no. That's the second problem one.

The students are clearly Uncertain about what to do with this problem as evidenced by S1 in line 193 and S3 in line 195. It is also possible that the students do not actually understand the problem statement or question. In fact, S1 realizes at the end that she had been looking at information concerning a different problem altogether (line 206). However, I do not have enough evidence to say they don't understand what is being asked: only that they don't understand what they need to do, populating the Procedural component only. They are, however, trying to figure it out. This is evidenced by S1 in line 197. There are also a couple references to not knowing how to estimate a particular quantity ($k_{s,i}$ in this case), as well as S1 making a

statement about the mass of nitrogen (lines 197 and 205 respectively).

At first, it may seem odd to describe the students' behavior as Collaborating. But they are, in fact, creating a collective struggle together. Their "I don't know's" mutually reinforce each other (lines 197 - 201), and they each bring unique information to the creation of the Issue (lines 197 and 205). S1 spends more time on the quantity to be estimated, while S3 seems to generalize more about not knowing how to start but also adds that they know the mass of nitrogen.

Additionally, these expressions and hesitations reveal that they are aware they are having trouble (SPI - P - Uncertainty). Not only do they express not knowing, but they refer to the whiteboard and the PC to try to gather information that will help them. They never, however, make a decision on any opening move of the problem. In discussing their struggle, but not making any definitive moves, the students' Issue only contains Uncertainty. There is no Error here because there is no action.

During the Interaction

An interaction with the GTA on getting started may be initiated by the students or the GTA, but the GTA directs (TAdirect) the conversation and does so mostly without seeking student input (Sinput). The GTA uses an Abbreviated diagnosis to determine what to focus on. Through this, the GTA focuses on the AI, adding more details to the focus than were present before the interaction.⁶ These details Address the Issue with Procedural talk. In half the data (three Issues), the TAFI also includes other components. Students express understanding of the GTA's focus, showing they've made some changes in their ideas of what moves to make toward solving the problem (Get, TAFI - Resolution). These features are highlighted in the diagram in Figure 5.8.

⁶This is identified by the mix-color TAFI components. The TAFI - P only differs from the AI - P in that the GTA is able to contribute more details where the students were completely absent of them beforehand. The Issue content boxes say the same or similar things, but the TAFI must add more detail. In this way, more content is brought up and discussed during the interaction than before. Other than pointing out these differences, I will treat the multi-colored components as the same in the remainder of this chapter.

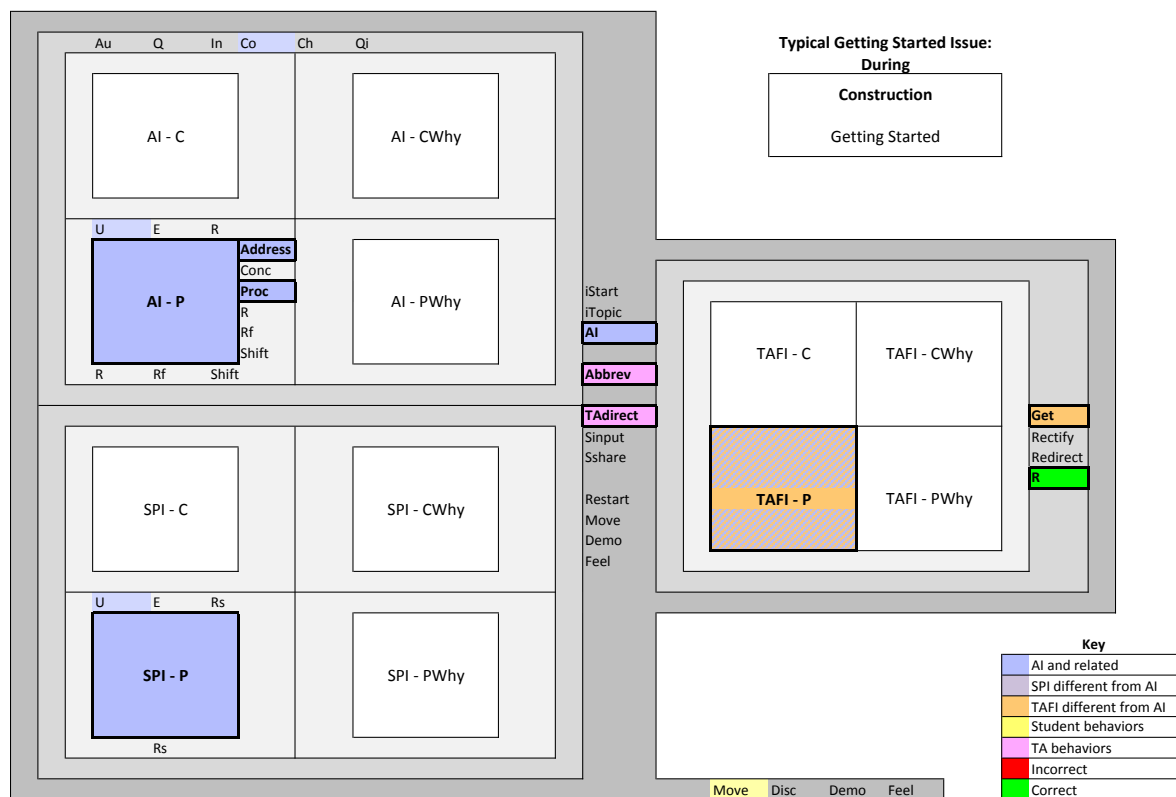


Figure 5.8: The Issue diagram for a typical Getting Started Issue. Highlighted, bolded features are those present during the interaction. Other common features are muted.

Continuing with the example, I will examine how this structure plays out. After struggling with the problem statement, the GTA approaches them, and an interaction ensues to help the students begin the problem. The GTA opens.

208 **GTA:** Did you figure out how to do this?

209 **S3:** Noooo

210 **S1:** Not yet. (shaking her head)

211 **GTA:** So this is, just the same technique as what you did for the previous one, but for E
212 only you use the one that's on the board, the equation for-

213 **S3:** How do we know the mass of nitrogen?

214 **GTA:** Okay, mass of the nitrogen, you should be able to get it in terms of amu units. So

215 you can either Google, or it will be in your periodic table, or... or I can give you directly.
216 **S2:** so
217 **GTA:** It's fourteen point zero six seven (14.067)
218 **S2:** fourteen
219 **GTA:** amu
220 **S2:** Okay (begins calculating on calculator)
221 **S3:** (begins writing on whiteboard $14.067 * (\textit{conversion})$)
222 **GTA:** And there's a conversion factor for your amu into kilograms. That's on the board.
223 **S1:** Oh, I see it. (begins writing out values on whiteboard)

In this particular case, the GTA had been watching these students for several seconds before beginning the interaction. Thus, in this example, Listening is the diagnosis. However, the first question from the GTA in line 208, followed by students' responses in lines 209 and 210, and then immediate help from the GTA (line 211) exemplifies the Abbreviated diagnosis shared by all other cases. An Abbreviated diagnosis is enough in this category (Getting Started) to allow the GTA to focus on the AI, matching its contents. Since there is very little information expressed by the students before the interaction - common with Getting Started Issues - the GTA adds more details to the TAFI than were present before the interaction. These details identify for the students the correct equation to use by pointing it out on the board (lines 211).

The GTA directs (TAdirect) this conversation by checking on students' present status and then giving them the information they need to begin to solve the problem (lines 208 and 211). As students ask for further physics content, the GTA obliges by giving it to them and also adds in an additional procedural move: convert the mass (lines 213 - 222). She uses Procedural talk alone to Address this Issue. Students express very little physics content relative to what the GTA provides.

In beginning, to write and calculate the mass conversion before the interaction ends, the students show they understand what the GTA is getting at (Get) for at least one piece of the solution, and so are able to begin the problem by the end of the interaction (TAFI - Resolution)

(lines 220 and 223). This marks a change in the moves they struggled with before the interaction.

Post-Interaction

Once the interaction ends, the students Move forward, beginning the moves necessary to construct their solution. The post-interaction diagram in Figure 5.9 shows this simple piece exemplified in the students' dialogue.

224 **S2:** You multiply it right?

225 **S3:** Yeah.

226 **S2:** (typing into calculator) Okay. Two point- can you write that down? Two point three
227 three five one two two. (2.335122)

228 **S3:** (writing 2.335122)

229 **S2:** E to the negative twenty six ($x10^{-26}$)...

230 **S3:** (writing $2.335122x10^{-26}$ for mass)

231 **S2:** So now

232 **S3:** All right. So square root... (writing $\omega = \sqrt{10/\dots}$)

They complete the mass conversion (line 230). S3 then immediately begins writing down the equation for omega (line 232). This shows that they have gotten enough information to begin constructing a solution and Move forward doing so.

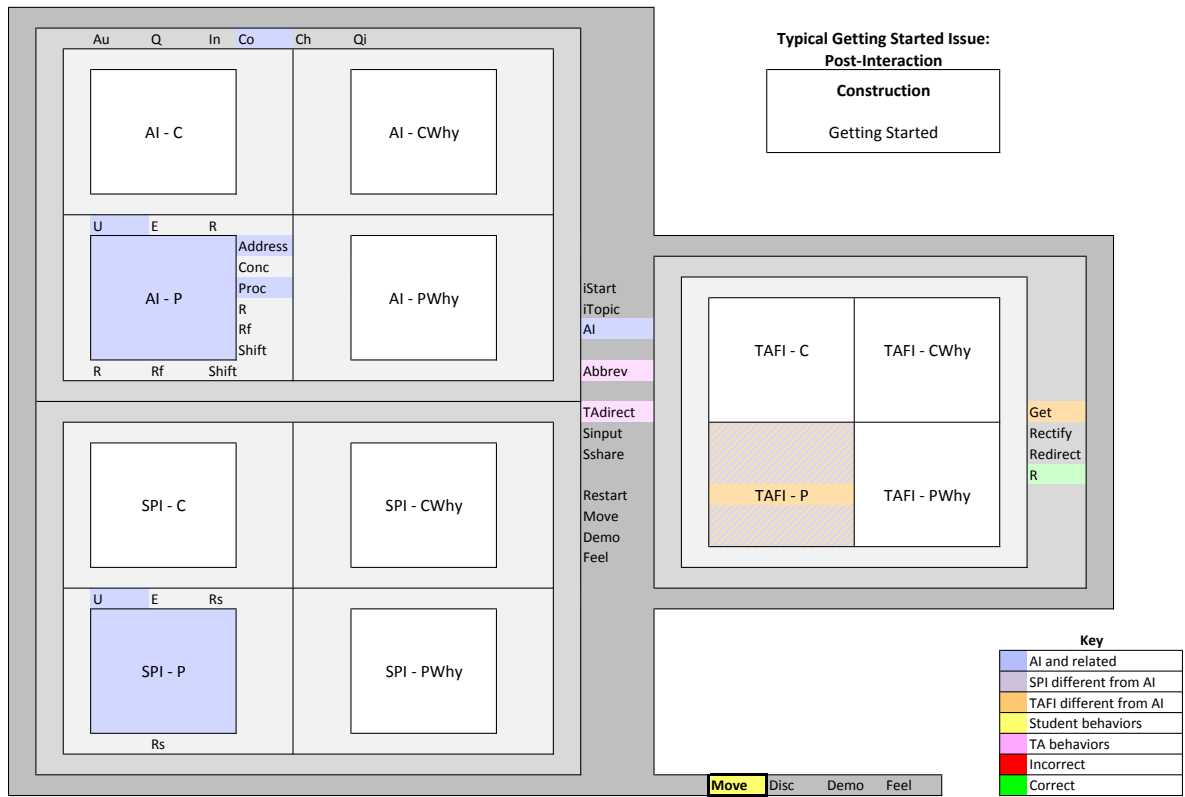


Figure 5.9: The Issue diagram for a typical Getting Started Issue. Highlighted, bolded features are those present after the interaction. Other common features are muted.

Reflections on the Typical Getting Started Issue

I start with a review of how the interaction is situated in the students' process. In this category, the students' processes before the interaction begin with confusion about the procedure needed to solve a problem (AI - P). Students are typically in agreement on being Uncertain about what to do to solve the problem. During the interaction, students' confusion with what procedure to begin and how is narrowly Addressed (Procedural talk). Their process changes to one of being able to begin constructing a solution to the problem (TAFI - Resolution). Though this change is sometimes only seen clearly after the interaction. After the interaction, this change in process is solidified as students' Move forward, taking the first steps to construct their solution. The interaction is situated in the students' process such that the GTA describes at least some

procedural moves needed to begin constructing a solution (detailed TAFI - P) after briefly diagnosing the students' confusion (Abbreviated).

The interaction is typically situated vary narrowly around the procedure needed for whichever particular problem the students are attempting to solve.⁷ It may be more useful to examine how the interaction is *not* situated in the students' process. The interaction does not situate in such a way as to focus on developing students' ability to work past their initial confusion - development of problem solving skills - or discussing the physical situation, and thus physics content in which the particular physic problem was created. The focus instead is on how to proceed to solve the specific problem given. This narrower focus in the typical case can be inferred from the Abbreviated diagnosis - enough to diagnose confusion, but not much else, the lack of multiple components in the TAFI, and the lack of Sinput and Sshare. Presence of those features would show an effort to get students involved in either the bigger picture of the problem statement, the process of working through their own confusion (which I expect would also involve more focus on the problem statement), or both.

The content of the AI and the lack of Sinput were the most interesting features in the Getting Started Issue category. I'll continue with a reflection on these.

Content of the AI and TAFI

In this Issue category, it is interesting that students express not knowing how to get started on a problem but rarely express not understanding the problem statement or the goal of the problem. There is a focus on doing (or not knowing how to do) in their speech, but there is no evidence from the students that they understand even what the problem is stating or asking. They simply don't talk about the problem in that way.

The GTAs also focus on the solution procedure, matching the students' AI - P, and sometimes surrounding physics content, but rarely on the problem statement itself.⁸ Focusing on the problem statement would add a component to the TAFI that could uncover more about

⁷This is not always the case as I describe in Section 5.2.2.

⁸An example of a GTA focusing on the problem statement is described below in Section 5.2.2.

the students' Issue than they express before the interaction.⁹ I should note that I do see more discussion of the problem statement and ideas in general from the most experienced GTA. I do not from the rest, but I think this could be informative for the GTA as well clarifying for the students.

Sinput

More information is being revealed and organized during the interaction than the students expressed beforehand as shown by the mostly matching TAFI and AI. However the lack of Sinput¹⁰ shows that students are not commonly encouraged to contribute to that organization of information.

The lack of Sinput does not mean the students do not contribute, only that they are not encouraged to do so. They may still share moves or physics content within the interaction. The framework does not necessarily pull this out. However, given their confusion before the interaction, I think the chance of them participating without encouragement during the interaction is slim. As in the above example, there are a few questions being asked by students for additional information or clarification (line 213), but not much more than that, and those instances are not pulled out in the framework. Thus, most of the additional physics content and procedural moves to get students started comes from the GTA during the interaction.

Given the students' quiet staring, perplexed verbalizations, and lack of organized information before the interaction, the lack of Sinput during the interaction indicates a missed opportunity to help students identify ways in which they might figure out how to deconstruct the problem statement and begin a solution when they feel stuck - an important problem solving skill. The presence of Sinput would indicate an attempt by the GTA to pull information or

⁹The GTAs do in fact add TAFI components in three of the six interactions, so that part is not uncommon. In the first of these, the GTA adds information about the physics concept without talking about the problem statement. In the second, the students focus on the problem statement and so does the GTA. And in the third, the students are a bit farther along in batting around ideas and so the interaction is more targeted to discussing those ideas.

¹⁰Sinput is present in two of six cases, but only under one GTA. I discuss differences in Sinput across GTAs in Section 5.6.

strategy out of the students, thus, giving them some responsibility for as well as guidance in organizing their thoughts in this phase of the problem. There may be cases in which students have an Issue getting started and are able to work through the Issue on their own. In these cases, there most likely would not be an interaction with the GTA, so this research does not pull out those times. Thus, I can not know whether or not the students work through some of these Issues on their own.¹¹ I note only that *interactions* concerning these Issues are opportunities for GTAs to help students develop this problem solving skill, but the framework indicates these opportunities are more often missed. This finding demonstrates the value of the framework for its ability to highlight these kinds of opportunities and identify how the GTA responds to them.

Resolution

Finally, I notice that the Resolution feature of the AI - P during the interaction is not highlighted but that of the TAFI is. This differs from the typical story of all data that shows the AI - P Resolution feature is common across the dataset. However, some form of procedural change (R, Rf, or Shift) does happen for the students in all but one Issue in this category. A full Resolution (R) does not always happen *during* an interaction. However, the students do fully Resolve or Functionally Resolve the Issue in most cases either during *or after* the interaction. That the TAFI is very similar to the AI and Resolved is further evidence that a change has happened in the students' process during the interaction that leads to an eventual Resolution or Functional Resolution.

5.2.2 Getting Started: An Atypical Case - Encouragement of Student Input

When I looked at the presence of the GTA's encouragement of student input (Sinput) - an indicator that a GTA is attempting to include students in the dialogue in some way - there

¹¹One data segment from the Solution Approach category contains dialogue in which students express confusion getting started on a problem and then work through their confusion to begin constructing a solution. An interaction then occurs concerning an Issue they created in the early stages of constructing a solution. Thus, I do see students working through their confusion at least once, but this framework does not identify that case specifically because there was no interaction with the GTA concerning the students' confusion getting started.

was one GTA of three who encouraged it in his interactions with students within this content category (Getting Started). In the cases here of encouraging student input, there is a valuable difference in the unfolding storyline. Students take a more active role in establishing the appropriate physics content and procedural moves, thus contributing to the process of interpreting the problem statement and beginning to construct a solution. I review one of those cases here.

In this case, students are on the same problem found in Figure 5.7 - finding the ΔE of two adjacent energy levels in a nitrogen molecule - and in a similar situation to the students in the example above. The full diagram for this case is shown in Figure 5.10.

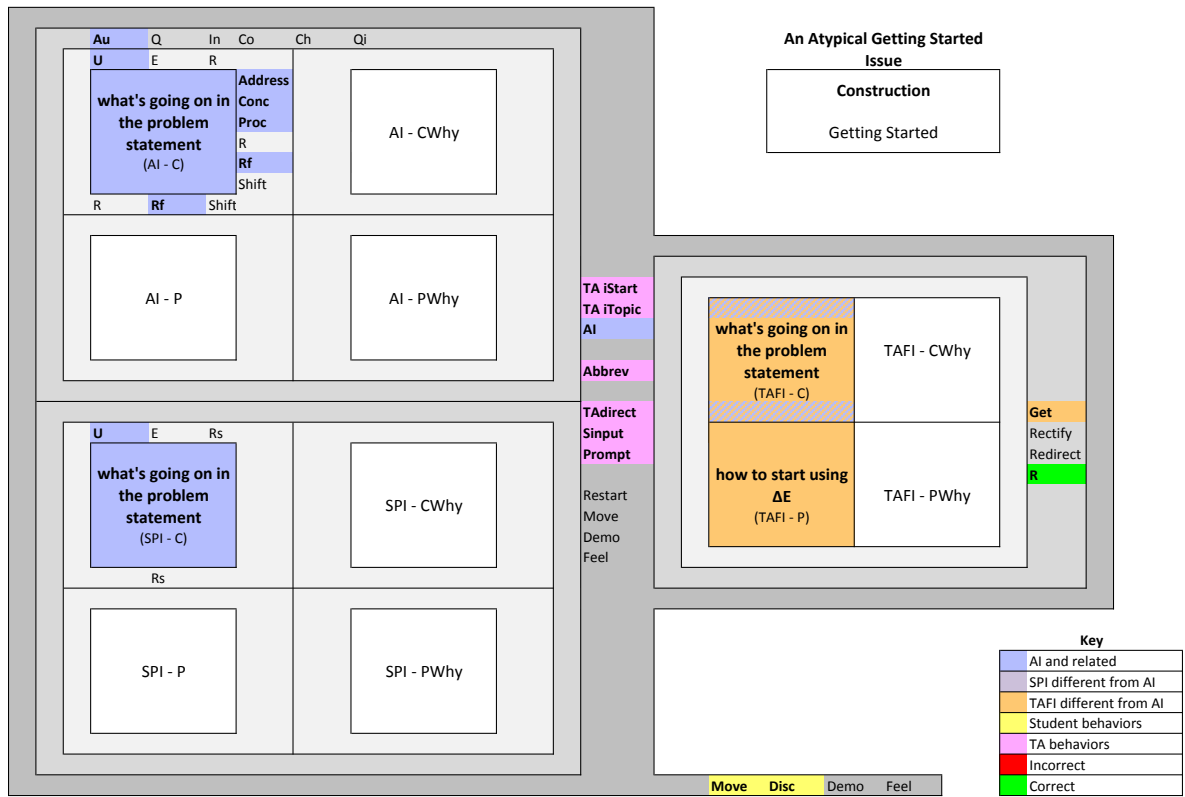


Figure 5.10: An example Issue diagram showing an atypical Getting Started Issue from the Spectra Lab Problem 2. This diagram contains only *some* features present in the typical story (AI, U, Address, Procedural talk, SPI, Abbrev, TAdirect, TAFI - P, Get, TAFI - R, Move). While the U, Address, and Proc features do exist in the typical story, note that the features in this example concern the AI - C component, which is atypical. The remaining features are unique to the example. All features present are highlighted.

A glance at the diagram reveals a few prominent atypical features: a Conceptual instead of Procedural AI, a multi-component TAFI, and encouragement of students' input (Sinput, Prompt). I will mainly focus on the atypical feature of encouraging student input during the interaction. I will start, however, with the creation of the Issue for contextual clarity.

- 233 **S3:** Oh my god. I don't understand this.
- 234 **S2:** Looked up in your book. Great. I don't have a book.
- 235 **S3:** I have a book. Here you go, recorder. (hands S2 a book)

236 **S1:** That has to do- I think it goes with
237 **S2:** center of mass stuff. (Flips through book)
238 **S1:** Okay, maybe it's a little bit... I know it's around- yeah. 'Cause these graphs deal with,
239 like, vibrational (looking through book too). Um, estimate the-... Estimate the difference
240 in energy between the two vibration... (reading the problem)
241 **S2:** Should we just ask?

This dialog shows that the students seem very Uncertain, similar to the above example of the typical story. They flip through their book in search of something (line 237), and re-read the question (line 238), but very quickly decide to turn to the GTA (line 238). They express almost no physics content, nor anything about procedural moves.¹² Their quick decision and lack of ideas expressed led to this creation being coded as Automatic. The interaction quickly follows.

242 **GTA:** How're y'all doin' ?
243 **S2:** We need directions, I dunno, um, directive something.
244 **GTA:** Okay, so,ummm, mmm-what's going on here-what have we got in the problem?
245 **S3:** Umm, uuuuuhm (laughs), I'm not sure. I just know there's-
246 **GTA:** Dah! We've got a diatomic molecule
247 **S3:** Right.
248 **GTA:** into two atoms of nitrogen.
249 **S3:** mmhmm

Initially, it seems as if the GTA is making an Active diagnosis as he probes the group for their thoughts on the problem statement (line 244). Unfortunately, after hearing S2's statement of Uncertainty (line 245), he cuts off her next statement and begins explaining (line 246), making the diagnosis Abbreviated. The initial attempt at an Active diagnosis is not pulled out by

¹²Since they never talk about what or how to start a procedure, I identify them as being stuck on the problem statement. Thus, the students only create an Issue in the Conceptual component in this case. I acknowledge that they probably also have an Issue in the P component at least, but they do not express confusion towards what to do so much as towards what is going on in the problem.

the framework. I found it valuable to identify where the attempt falls short, however, because this indicates students have lost the opportunity to express their ideas, and the possibility of understanding that idea better is lost as well.

Moving on in the interaction, the help with getting started unfolds. There is a long procession of ideas and directions here. I've colored all the GTA questions and directions in green, so they are more clearly visible. In one or two cases, the GTA's tone suggests student participation, even if the ordering of the words do not specifically request it. Additionally, lines 246 - 249 are repeated from above, but the line numbers continue to progress.

250 **GTA:** Dah! We've got a diatomic molecule

251 **S3:** Right.

252 **GTA:** into two atoms of nitrogen,

253 **S3:** mmhmm

254 **GTA:** and it says we're going to represent the bond between these two nitrogen atoms, as a
255 quantized harmonic oscillator- So let's draw that. Let's draw your picture. What does that
256 look like to you?

257 **S2:** So, two balls, you think? (beginning to draw Figure 5.11)

258 **GTA:** All right. Two balls. Okay.

259 **S2:** Has it got a spring in between them? (continuing to draw Figure 5.11)

260 **GTA:** Ah, nice! All right, that's what I thought. That's exactly what I picture this as being
261 like. All right. So, um... So, think about it vibrating, and then, all of a sudden it's got some
262 packet of energy, and it's gonna vibrate faster. It jumps a little bit of energy.

263 **GTA:** Quantized harmonic oscillators jump in quantized amounts, in energy levels. Re-
264 member this little energy level well that we had (gestures on the whiteboard in a sweeping
265 movement to mimic a potential well).

266 **S2:** (begins drawing the well with the energy levels)

267 **GTA:** And the spacings are evenly spaced - just like that.

268 **GTA:** We're trying to find one jump. The Delta E formula to determine - will determine

269 how much energy it takes to go from one to one is, (pointing to one level then one level up)

270 **S2:** Delta E is equal to - is the E zero plus omega? hbar? (writing out $\Delta E = E_0 + \omega\hbar$)

271 **GTA:** You got it, except that's going to be the energy level for (erasing Δ)

272 **S2:** Oh, okay.

273 **GTA:** the-all right

274 **S2:** Yeah. That's right.

275 **GTA:** Okay, but this is your change. (circling $\omega\hbar$). That's how much energy it takes to go

276 from one- how much extra energy it takes to go from one to the next. (erases all but $\omega\hbar$)

277 **S3:** So really, we're just calculating W hbar?

278 **GTA:** Yeah. Omega hbar.

279 **S3:** Oh, omega.

280 **GTA:** So what's omega?

281 **S2:** Omega is K S I over M A (writing out $\sqrt{ks_i/m_A}$)

282 **GTA:** Yeah. And that's the mass of a-

283 **S2:** Atom.

284 **GTA:** Atom. Which atom are we talking about again?

285 **S3:** Nitrogen.

286 **GTA:** Nitrogen. So if you can figure out the mass of nitrogen...

287 **S3:** One atom.

288 **GTA:** you're getting there. I'll be right back.

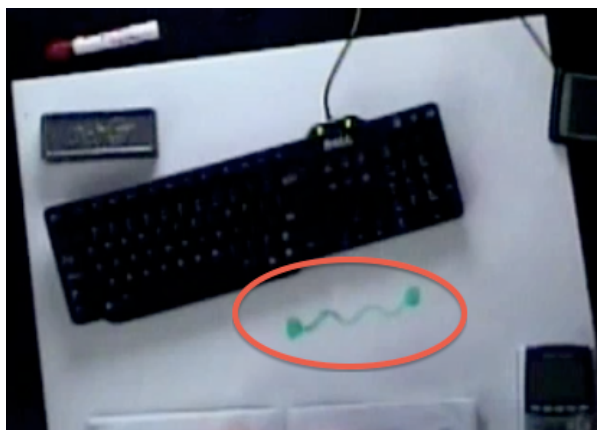


Figure 5.11: Students' whiteboard work shows S2's drawing of the ball and spring model of a quantized harmonic oscillator of a nitrogen molecule.

As in all typical cases, the GTA is fully directing the interaction (TAdirect). He is guiding the topic and the flow to get students up to speed on the problem (lines 260, 267, and 268). He also spends much of the interaction describing the physics and physical situation (lines 250, 254, and 260 -263) (TAFI - C/PWhy). The students seem to catch on as evidenced by the Resolved TAFI (Get, TAFI - Resolution).

There are a few unique features as well, and I'll focus on the three that seemed to most influence the students to express physics content. The first is that the TAFI includes both a C and a P component. The TAFI matches the AI - C by focusing with more detail on the problem statement (lines 250, 254). The GTA then moves on to focus on how to solve the problem, the TAFI - P component (line 268). In this way the GTA presents a more complete story of the problem, the physics content *and* moves, rather than focusing solely on a procedure. This however, is only influential in combination with two other features.

The second and third features are the GTA's encouragement of student input (Sinput) and Prompting for students' ideas (Prompt). While he describes the physical situation, he has students draw out a picture of what that situation looks like. He specifically uses the question, "What does that look like to you?," in line 254 Prompting S2 to draw out her personal idea of the physical situation (lines 257 and 259). The following questions are more targeted,

asking students to remember formulas and checking singular pieces of information (lines 268, 280, and 282). Throughout the interaction, this GTA encourages students' contributions as he simultaneously checks their knowledge of the appropriate physical situation and equations to use. In this way, he pulls the physics content they will need to solve the problem out of them.

Finally, along with Resolving the TAFI, students have Functionally Resolved (Rf) the AI - C. The Resolution of the TAFI indicates the students have expressed an understanding of the procedural moves to make to construct the solution (lines 270, 277, 281 - 285). This occurred mostly by way of the GTA drawing the content for the procedure out of them. The Functional Resolution of the AI - C indicates that some change also occurred for the group in their expression of physics content toward the problem statement (evidenced by the Prompting of their ideas) but that they still did not exhibit confidence or certainty in the content they were expressing.

Reflections on the Atypical Getting Started Issue

This example shows a Getting Started Issue in which the students have trouble understanding the problem, and the GTA meets them where they are struggling. The GTA then pulls information and ideas out of the students during the interaction. The GTA still organizes that information for the students, but the students participate in the process as well. The students' process again shows one of confusion, but the specific words reflect confusion in understanding the problem statement (AI - C, Collaborate), rather than how to begin constructing a solution (AI - P). During the interaction, with the GTA's guidance (TADirect), the students' process changes to one of participating in a discussion that analyzes the problem statement, describing the physical situation of the problem (TAFI - C, Sinput, Prompt). Their process then changes further to participate in mapping out the physics equations needed to begin constructing a solution to the problem (TAFI - P, Sinput). By the end of the interaction, the students' process has changed to focus on a piece of an equation they will use and begin working on the procedure of constructing a solution (TAFI - Resolution). The interaction is situated such that it serves

to both analyze the physical situation embedded in the problem statement *and* map out the physics leading to the procedure the students begin using to solve the problem (TAFI - C, TAFI - P). It is also situated to encourage the students' participation in this process (Sinput, Prompt).

Contrasting how the interaction is situated in the students' process in the typical Getting Started story, this interaction includes a multi-component TAFI that indicates the GTA is focused on the problem and physical situation as well as on the procedure needed to solve the problem. The presence of Sinput and Prompt indicate that the GTA encourages students to participate in changing their process, rather than relying fully on him to change it for them. This example still included an Abbreviated diagnosis, demonstrating that the interaction is not situated to begin fully from students' thinking. This may be partly why I can not determine whether or not the AI - C is fully Resolved.

The students begin with an Issue of understanding the problem statement. However, this is not necessarily revealed to the GTA in the beginning, as S1 begins with "We need directions." So I find it very interesting that the GTA brings up the problem statement by asking the students about it, rather than about the procedure. I contrast this to other GTAs' tendencies to jump right into how to do a problem when presented with confused students. I don't know why the GTA chooses to begin with the problem statement, but in doing so he creates a more complete picture of the physics content and the procedure, rather than a picture of a procedure alone. I can speculate that the students did not necessarily tip the GTA toward the problem statement as their initial question to him specifically asked for directions (line 243). Thus, I attribute the reason behind his focus to something more intrinsic and hidden.

The presence of Sinput and Prompt shows that the GTA is including the students in the creation of this more complete picture. In this example, the GTA includes the students quite a bit more than is seen in many interactions. In so doing, he helps students contribute both physics content describing the physical situation as well as the formulas needed for the procedural moves. I contrast this to the typical story in which students are not encouraged to contribute

content or procedural moves, and content is added more by the GTA than by the students. This example illustrates what an interaction that encourages student participation might look like in this category. There is continued use of GTA encouragement to pull out from students the physics content that will help them through the problem. Each bit of content is surrounded by the GTAs' explanation of the physics involved. While I recognize that the conversation is still directed by the GTA with the questions targeted towards specific ideas and formulas, the GTA's encouragement of student participation here at least puts some responsibility for analyzing the problem and beginning to construct a solution back onto the students.

The identification of Sinput brings up a limitation of the framework as well. The framework does not specifically pick out the degree to which the students are involved in the interaction. In this example, the GTA asks several targeted questions and one more probing question for which a student draws out an image. In other data, just one targeted question or one probing question is asked, after which the student is cut off. This is a difference I would eventually like revealed in the framework. I reflect a bit more on this below in Section 5.7.

I will move on now to the next sequential stage students create Issues during a problem - within their solution approach.

5.2.3 Solution Approach (23 Issues): The Typical Story

Once students have gotten started on a problem, they may create Issues concerning specifics of their solution construction. These are categorized as Solution Approach Issues, since they appear after students have begun constructing a solution, but before they begin executing the details to find an answer. These Issues include, but are not limited to, selection of physics principles, or specific terms within them to be used in the solution; understanding the physical situation or physics model being utilized; and how to find specific quantities.

This category is very different from Getting Started in that there is quite a bit of variation in the diagrams of each Issue. In Getting Started, the common features I pulled out created a fairly complete story of the Issues. Here, there are not enough common features to tell a truly

complete story of the Issues. However, I will pull out the features of the framework that are most common in these Issues, and tell their story to highlight what can be said about the Issues together. I will then discuss some less common features and stories valuable to the results. I continuously show the example diagrams next to the diagram of the typical story to clearly highlight the variation of Issues in this category.

Students tend to construct Solution Approach Issues as they think through, with their group members, what to do about different pieces of a problem. In many cases, reasoning or conceptual ideas are also present. The group works together, often with at least one question being asked during the creation of the Issue. Students make an Erroneous move that will not help them find the correct solution. Sometimes this includes an Error in their reasoning as well. They also express Uncertainty about their moves. Students begin the interaction, and the GTA helps students Resolve the Procedural component of their Issue. Typically, the discussion includes encouragement of students' input. Afterward, the students can Move forward with their solution construction. The diagram for this typical story can be seen in Figure 5.12.

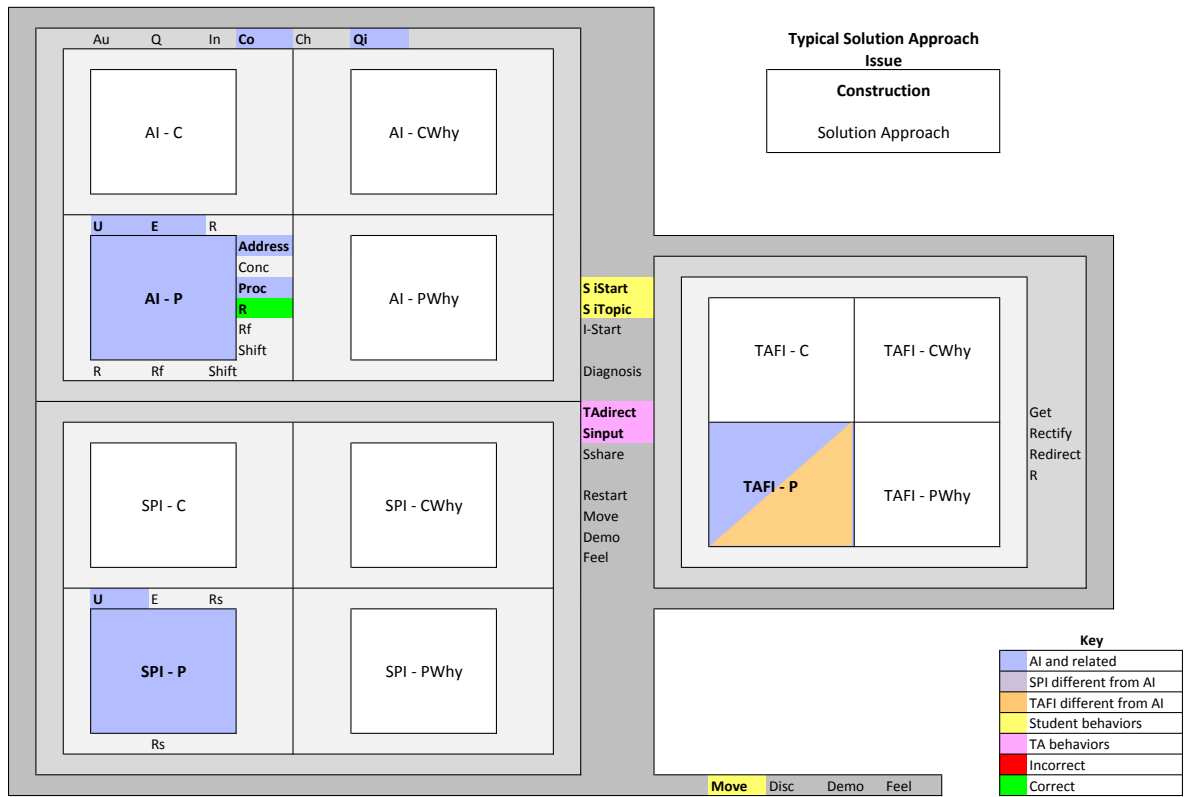


Figure 5.12: The Issue diagram for a typical Solution Approach Issue. Features that are present in at least 15 of 23 Issues are highlighted. The TAFI - P is colored both orange and blue as neither was dominant.

There is a bit more going on here in the creation of the Issue and during the interaction when compared with the common features found through the entire dataset. I examine each temporal section of the framework individually to understand this further and piece together the typical Solution Approach story.

Pre-Interaction Creation of the Issues

Most Issues in this category contain a Procedural component. More than half include at least one other component as well. This tells me that most of the other components present in Issues throughout the entire dataset are present in this category, indicating that most of the physics

content expressed outside of AI - P is concentrated in this category as well. Most of these Issues are created Thoughtfully and typically include students Collaborating (Co) and asking each other Questions (Qi). Typically students are aware of the presence of an Issue. While the SPI contains only elements of Uncertainty, the AI contains both Error and Uncertainty. Figure 5.14 shows the pre-interaction Issue creation diagram.

I will examine this structure more closely through a couple examples from the data. Before doing so, I note that each Issue is unique, so no single Issue is fully represented by the typical story. It would be unfair to the data and the study if I attempted to reduce these Issues to their typical story alone. Thus, as I describe the following examples, I will not only identify the typical features, but some of the less typical features of interest as well.

The first example is the same one I used in Chapter 4 to illustrate the framework. It is taken from the Ball Toss Lab. Students are attempting to calculate the initial speed of their ball after it is tossed using the energy principle. The specific instructions can be found in Figure 5.13.

Ball Toss - Energy Principle

Using the **Energy Principle**, use your experimental observations to determine the initial speed.

- **Note:** Do **NOT** use numbers (except for zero) until asked to do so, and be careful of signs.
- Use m for the **mass** of the ball, v for the initial **speed**, and Δy for the maximum **height**. Use g to represent $+9.8$ N/kg.
- For the **system** of the **ball**, write the **Energy Principle** for *this specific situation*
 - Initial state: just after the ball leaves your hand
 - Final state: when the ball reached its maximum height
- Solve for an expression for the initial speed, v . (**Note:** expression should have **NO** numbers!)

CHECKPOINT: Compare your results with another group.

- Now use your experimental numbers to predict the initial speeds for each of your two trials.
- Show your calculations on your whiteboard.
- Check your units and the reasonableness of your values.

Figure 5.13: The problem statement for finding v_i of the ball using the energy principle in the Ball Toss Lab.

Students here are trying to decide whether or not their work term should be zero. The pre-interaction Issue creation diagram for this example is given in Figure 5.15.

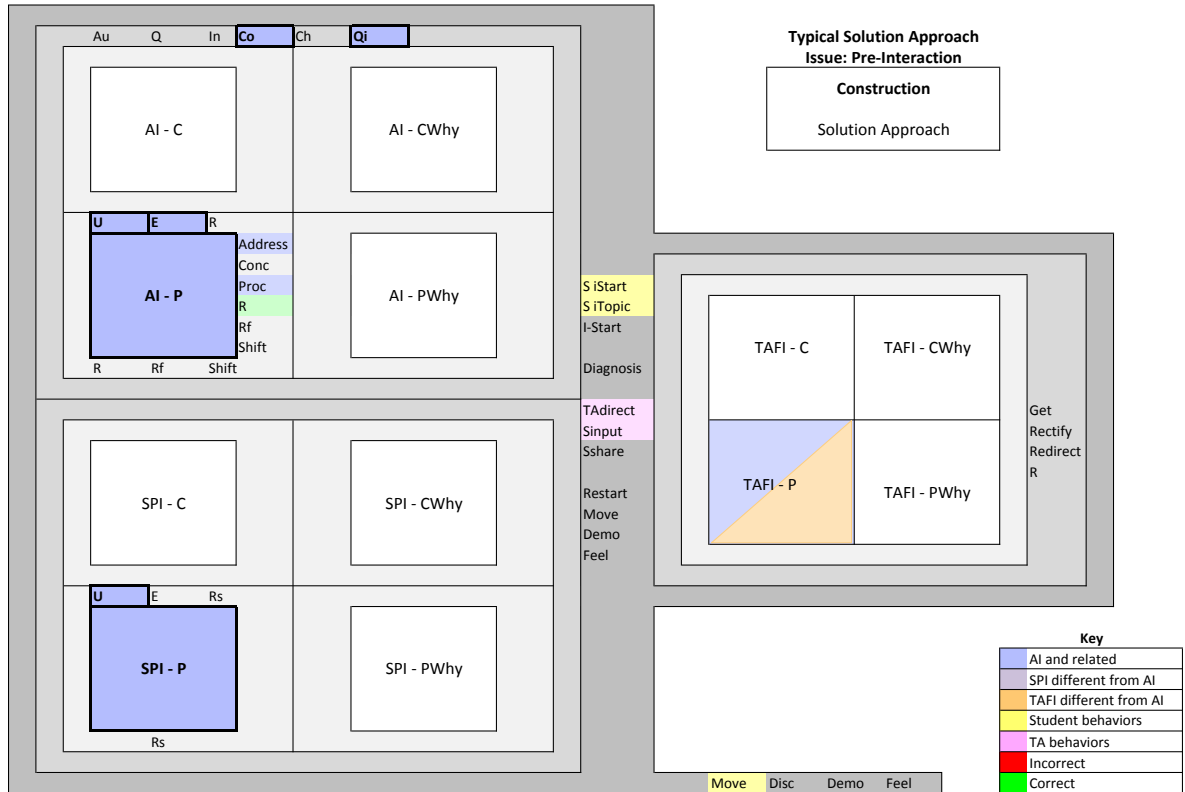


Figure 5.14: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present before the interaction begins. Other common features are muted.

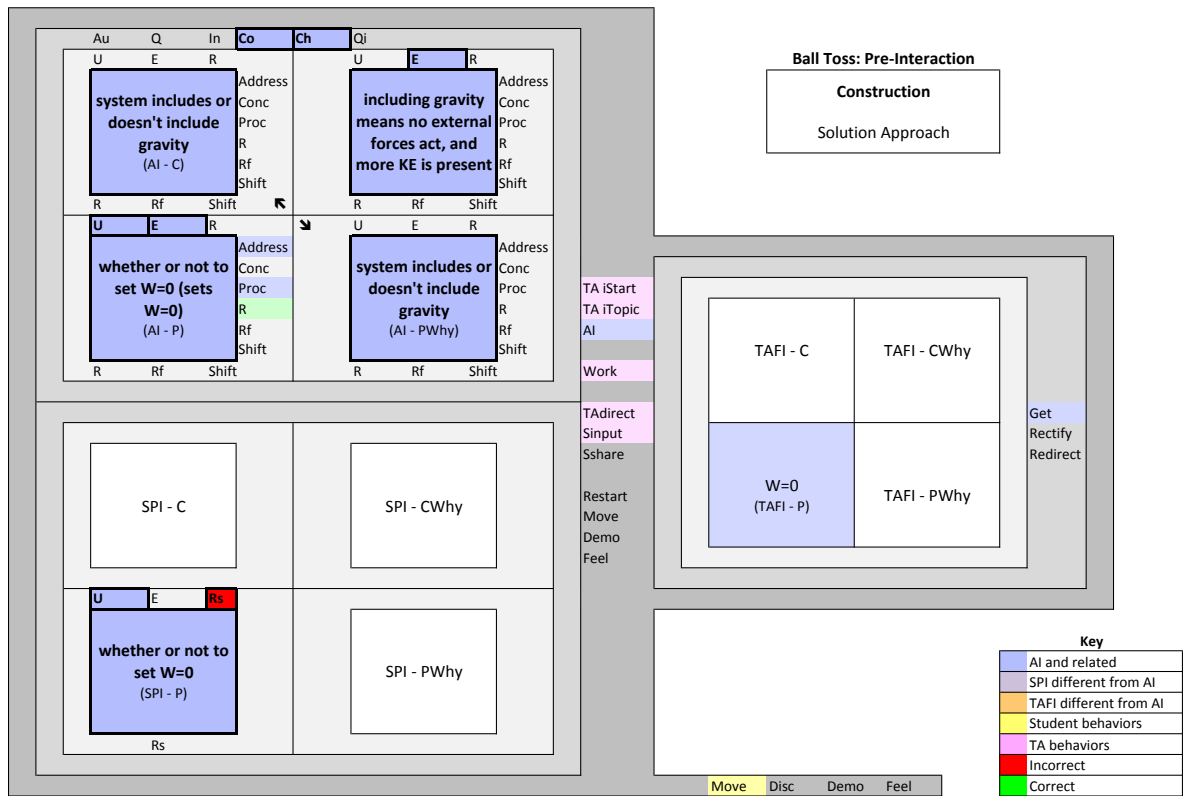


Figure 5.15: An example Issue diagram for a typical Solution Approach Issue from the Ball Toss lab. This diagram includes most features of the typical story (excluding Qi) as well as many features unique to the example. Highlighted, bolded features are those present during the interaction. Other features are muted. AI - P, U, E, Co, SPI - P, U are also present in the typical story Issue creation diagram. The two diagonal arrows indicate the C and PWhy components are identical.

By comparing this example to the typical diagram, I identify both similarities and differences. I'll account for both in describing this example, footnoting the less typical pieces. Students' energy principle is written out as $\Delta K = W$. S1 begins.

289 **S1:** Change in kinetic energy equals work. Ah, work is zero, because you're- it's the sur-
290 roundings... well...

291 **S2:** Well, then, how do you calculate the velocity if work is zero?

292 **S1:** 'cause your kinetic energy final equals fin-K, no, it needs...

293 **S2:** So...

294 **S1:** In this scenario, um, kinetic energy's going to be one half m v squared.

295 **S2:** And work,

296 **S1:** So it's going to be your final velocity minus your initial velocity.

297 **S3:** So final velocity equals initial velocity.

298 **S1:** Then your work- Your work is either going to be your gravity calculation then, or it's
299 going to be zero.

300 **S3:** It should be zero.

301 **S1:** Cause if you're choosing your surroundings to be, um, just the ball, you have to take
302 into effect gravity.

303 **S1:** But if you choose to make gravity, um, you includ e it in your system, then it's zero,
304 because there are no other forces acting on it.

305 **S2:** But it can't have zero in it, because zero makes everything zero.

306 **S1:** But, it doesn't necessarily, because if you chose to have the ball and gravity in your
307 calculation, your'e going to have more kinetic energy you have to calculate, so...

308 **S3:** (Writes out $1/2mv_f^2 - 1/2mv_i^2 = 0$ on the whiteboard)

309 **S1:** one half m v squared final...

S1 begins this Issue by introducing the Procedural component and an Error within it that immediately turns into a conflict for him (line 289). This conflict comes out both in the AI - P component of the diagram as Uncertainty as well as in creating an SPI in the P component. S2

heightens this conflict, Challenging S1's statements in light of the fact that the math will not work out in their equation if work is zero (line 291).¹³ S1 then explains his reasoning by invoking particular physics concepts (lines 298 - 303). This adds a C, CWhy, and PWhy component to this Issue.

Note from the dialogue that only the CWhy and P components contain an Error. S1's reasoning in the PWhy/C component is correct as he determines that work should be gravity if the system is just the ball and work should be zero if the ball and gravity are both in the system (lines 301 - 303). However S1 then reasons that the kinetic energy will somehow be different whether work is set to zero or not, reasoning incorrectly here (line 306). Since S1 seems to side more firmly with work being zero, S3 comes in a few times as a Collaborator, solidifying the procedural move of making work zero (lines 300 and 308). This is highlighted by the fact that that the SPI is Resolved incorrectly, leaving the Procedural component in Error.¹⁴

This examples shows the creation of the typical features of the Issue, as well as some less typical features - Challenges and SPI Resolutions. Also, S1 provides a large amount of reasoning behind his conflict, shown through the presence of multiple AI components.

During the Interaction

During typical interaction of Solution Approach Issues, the Procedural component of the AI is Addressed with Procedural talk and is Resolved before the end of the interaction. The interaction is begun and topic chosen by the students (SiStart, SiTopic). But, the GTA directs (TAdirect) the interaction in almost all cases, often including the students' input (Sinput). The TAFI typically includes a Procedural component, though it may not be the same as the AI

¹³Challenges are less typical.

¹⁴The SPI is Resolved in at least one component before an interaction in five of 20 Solution Approach Issues containing an SPI. It is Resolved incorrectly in four of those five Issues.

- P.¹⁵¹⁶ This reveals that, through the GTA's direction and regardless of whether the TAFI matches the AI, the AI - P component of the Issue students created is Addressed, and the students then change their idea of what procedural moves to make. The diagram is highlighted for what happens during the interaction in Figure 5.16.

Next, I follow the example Issue through its interaction. The diagram for this interaction can be seen in Figure 5.17 for comparison to the typical story.

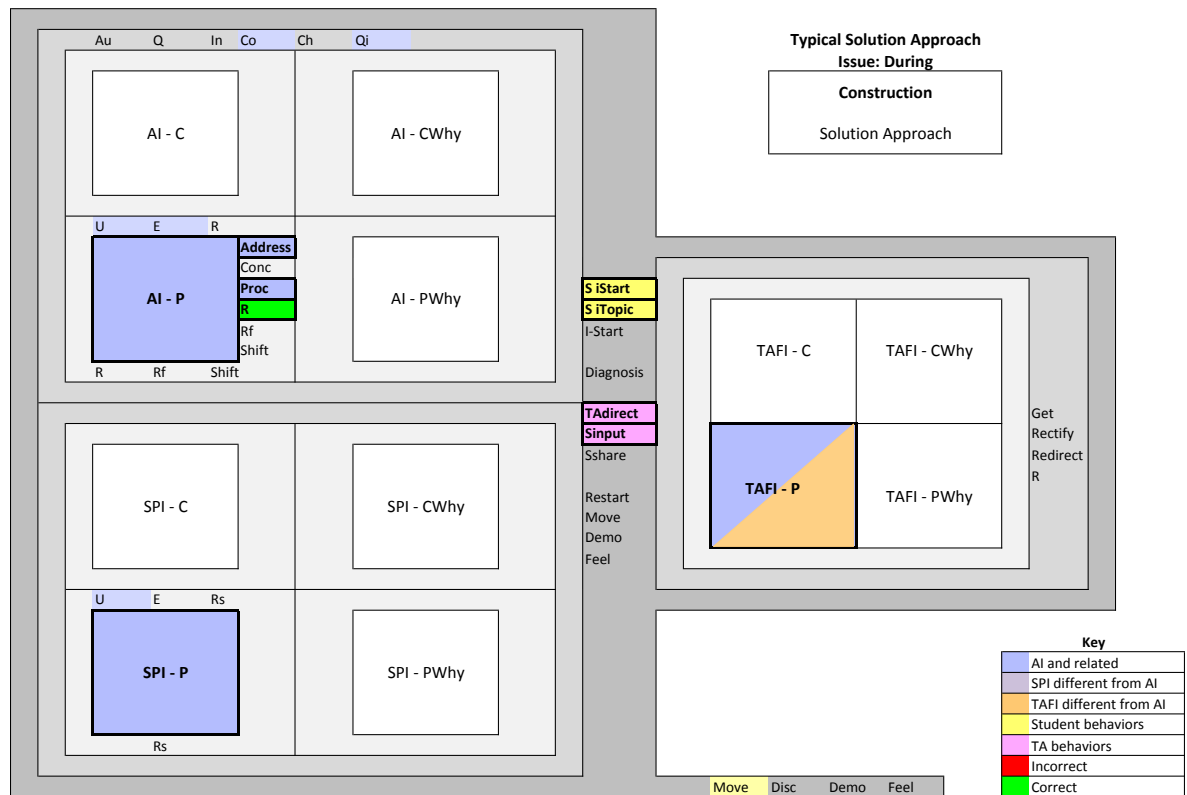


Figure 5.16: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present during the interaction. Other common features are muted.

¹⁵The TAFI - P does in fact match the AI - P in 10 of the 18 Solution Approach Issues containing a P component. And the TAFI perfectly matches the AI in general in 12 of 23 Solution Approach Issues.

¹⁶In 40% (nine Issues) of the data in this category, the TAFI - P component is accompanied by other components. This accounts for half of the multi-component TAFIs. The rest are spread among other categories (Getting Started, Unit Conversion, and Non-Issue). Multi-component TAFIs in Non-Issues fall under the Solution Approach category, though. See Section 5.4.

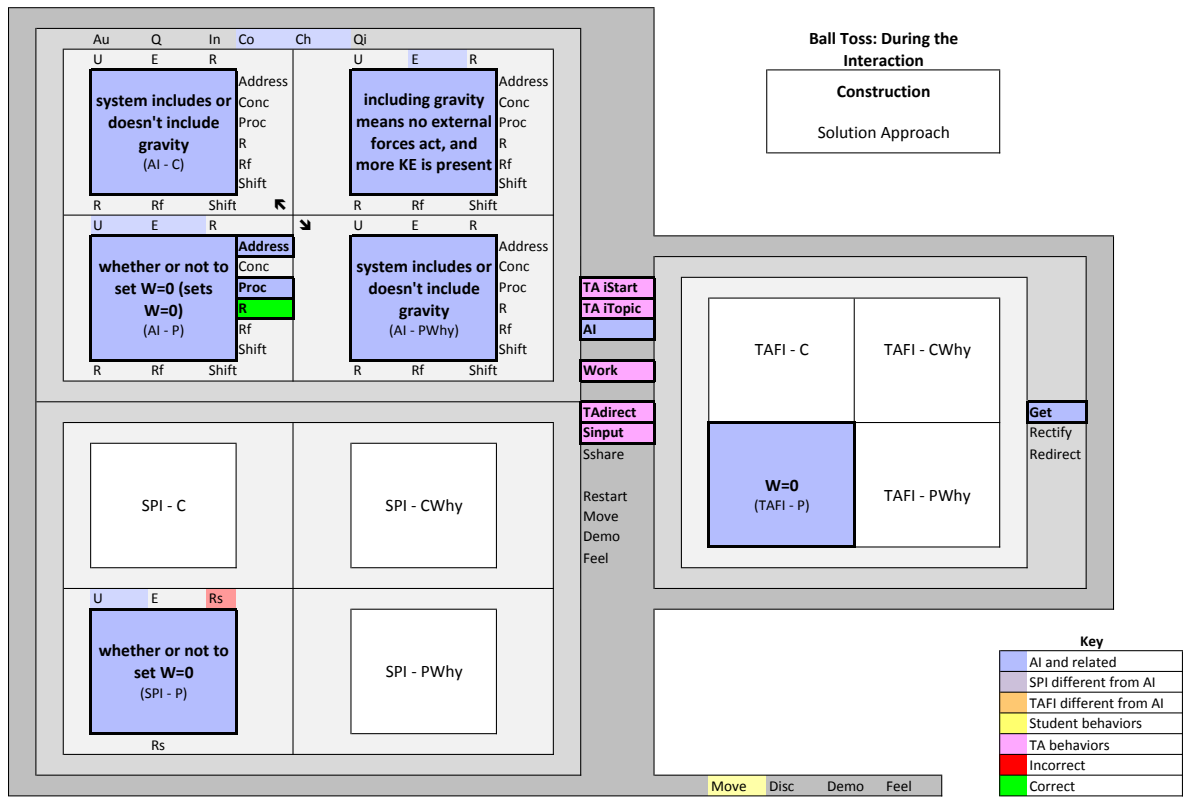


Figure 5.17: An example Issue diagram for a typical Solution Approach Issue from the Ball Toss lab. This diagram includes most features of the typical story as well as many features unique to the example. Highlighted, bolded features are those present during the interaction (All AI and SPI components are bolded regardless of whether they are Addressed during the interaction. Other features are muted. AI - P - Address, Proc, R; TAdirect, TAFI - P, and Sinput are also present in the typical story diagram. The two diagonal arrows indicate the C and PWhy components are identical.

The GTA approaches the students first, reviewing their whiteboard work as S3 finishes writing out: $1/2mv_f^2 - 1/2mv_i^2 = 0$.

310 **GTA:** Why is the work done zero?

311 **S2:** hmm?

312 **GTA:** Why is the work done zero?

313 **S2:** It's not?

314 **S1:** No. It's not zero.

315 **S3:** It won't be zero?

This interaction is very short in comparison to the development of the Issue. The GTA begins the interaction and selects the topic (TAiStart, TAiTopic). The GTA also directs (TAdirect) the interaction and Addresses the Procedural Error by pointing out the students' mistake in setting work equal to zero (line 310). The students read this as a correction to their term, rather than the start of a dialogue. They correct themselves, changing their idea of the the appropriate content behind the AI - P (line 314), and the GTA leaves (Get, AI - P - Resolution). The GTA's abrupt departure with no further probing of the students for their reasoning reinforces my inference that the GTA's original question was a correction to the students' mistake, not an attempt to discuss their reasoning.

The simple procedural correction within this interaction is most interesting when compared to the creation of the Issue. Quite a bit of reasoning with physics content is revealed in the Issue's creation that does not come out during the interaction. S1 immediately corrects his original Procedural Error, but it is unclear if this helped him correct his reasoning around it or construct a clearer model of energy conservation - things that may have come out had further discussion ensued during the interaction. However, the GTA focused only on the AI - P with work being zero. So it is only revealed that S1 Resolved the Procedural component.

Post-Interaction

As is typical, students Move forward with their solution construction after the interaction. This indicates that they have put the Issue behind them and continue to make moves to further construct their solution. A comparison of the typical Solution Approach post-interaction diagram and this example's post-interaction diagram in Figure 5.18 and Figure 5.19 reveals that they are identical.

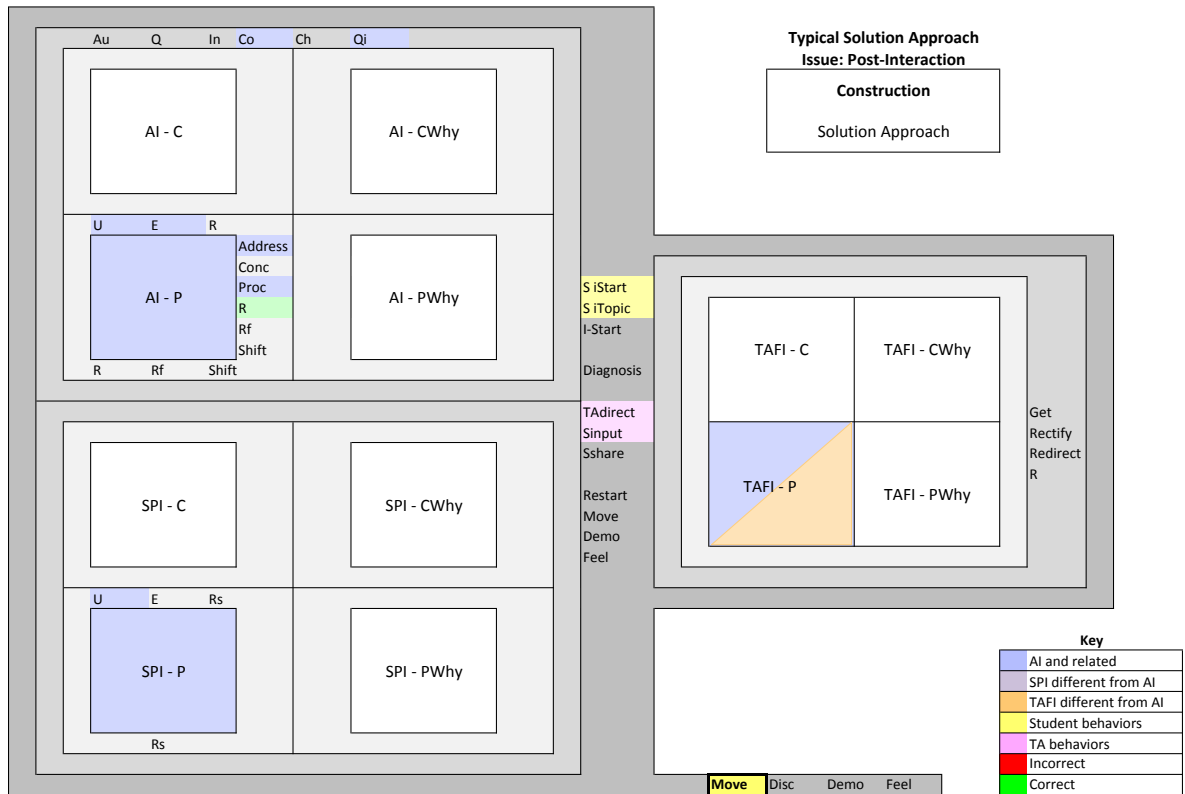


Figure 5.18: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present after the interaction. Other common features are muted.

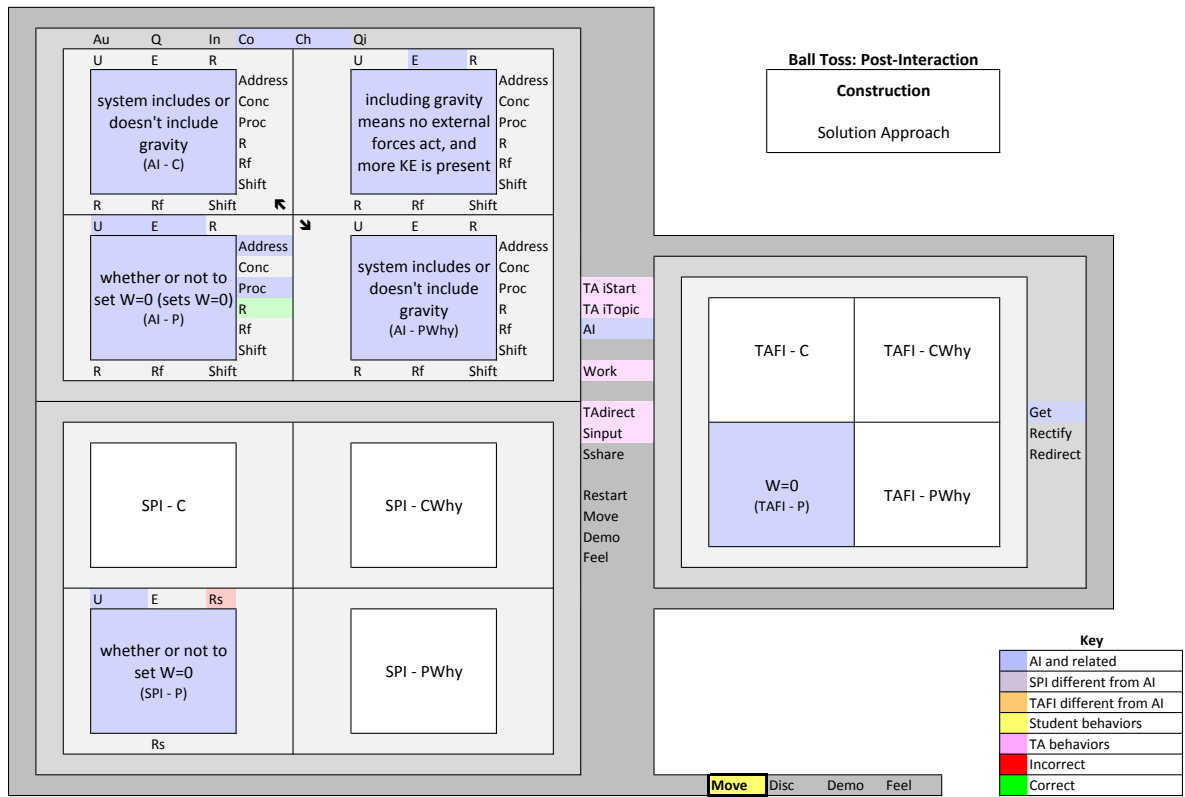


Figure 5.19: An example Issue diagram for a typical Solution Approach Issue from the Ball Toss lab. This diagram includes most features of the typical story as well as many features unique to the example. Highlighted, bolded features are those present after the interaction. Other features are muted. Move is also present in the typical story diagram. The two diagonal arrows indicate the C and PWhy components are identical.

The dialogue confirms that the students Move forward.

316 **S2:** Work equals... I can't remember the formula for work.

317 **S1:** No, work - Yeah, work is just, um, F_x times Δx plus F_y Δy plus, F_z Δz
 318 z , all added together ($F_x * \Delta x + F_y * \Delta y + F_z * \Delta z = W$).

Students leave the discussion of work in general and simply dive into the details of calculating it (line 317), Moving forward. There is no further discussion of reasoning, and so no further Resolution of the CWhy component of the Issue. The students' moves change as they add a formula for work, but there is no evidence of whether their reasoning has also changed.

Reflections on Solution Approach Example 1- Ball Toss

Compared to the typical story of the entire dataset, the big differences in this example are (1) the multiple AI components create a fairly complete argument and (2) the lack of focus on those components during the interaction. While the TAFI - P matches the AI - P, the GTA misses focusing on reasoning that S1 has fairly thoroughly fleshed out before the interaction (the AI -C/PWhy and CWhy). The focus on the procedure allows the students to correct their Error and Move on without further discussion of the reasons backing S1's initial argument. Also, the students do not take up this conversation and Resolve it later, leading me to think a discussion of the AI - CWhy component within the interaction is important for a Resolution.

The students' process is one of reasoning through the physics of the situation to identify the available options for procedural moves (AI - PWhy/C, AI - CWhy) and then selecting a procedural move (AI - P - Uncertainty, Error: settingwork to zero). The process involves creating Errors in both reasoning and the selection of the move. During the interaction the students' process changes from a selection of the wrong move, to recognizing that move as incorrect (AI - Resolution). After the interaction, the process of correction continues as students identify the correct formula forwork and begin using it to continue solving the problem (Move). The interaction is situated *only* to bring awareness to the students that they have made an Error in their move (Procedural talk, Work diagnosis, TAIiTopic, TAFI - P, TADirect).

Due to the students' process including a multi-component AI with indications of incorrect reasoning shown in Error, the interaction would ideally be situated to Address students' ideas as well as their procedure. This would be shown by a matching, multi-component TAFI and the inclusion of Prompt and/or an Active diagnosis. The lack of these features helps situate the interaction as solely bringing awareness to the Procedural Error.

I use this example to show that the typical features alone do not draw a satisfactory picture of the Issues in this category. The presence of multiple components, and the differences in the AI and TAFI are not wholly uncommon features in this category. Below, I'll reflect more on these kinds of features. I turn now though, to one more example that shows the uniqueness of

Issues in this category.

Solution Approach Example 2 - Issues in Fission

Since each Solution Approach Issue is quite unique, possibly due to the difference in solution approaches required by the different physics problems, I will explore another, slightly more complicated example. The following example will have many features of the typical story, as well as multiple less typical features. I will not re-describe the common features in general again. But I will include the typical diagrams along those of the next example for comparisons.

Pre-Interaction Issue Creation

In this next example, students are setting up a solution for the final total kinetic energy of two daughter nuclei after a fission reaction. The full problem statement and lead-in questions are presented in Figure 5.20.

Figure 5.20: Fission Problem Statement includes the problem story, the story diagram (the correct order of events is c, a, b), and the first four questions asked of the students. Focus is on the last of these questions, but may take dialog and interactions concerning the first three questions as they appropriately pertain to the last question.

Fission Problem

For some isotopes of some very heavy nuclei, including nuclei of thorium, uranium, and plutonium, the nucleus will fission (split apart) when it absorbs a slow-moving neutron.

For example, uranium-233, with 92 protons and 141 neutrons, can fission when it absorbs a neutron and becomes uranium-234. The two fission fragments, called "daughter" nuclei, can be almost any two nuclei whose charges Q_1 and Q_2 add up to $92e$ (where e is the charge on a proton), and whose nucleons add up to 236 protons and neutrons (U-234, formed from U-233 plus a neutron).

One of the possible fission modes involves nearly equal fragments, palladium nuclei (Pd-117) each with electric charge $Q_1 = Q_2 = 46e$. The rest masses of the two daughter nuclei add up to less than the rest mass of the original parent nucleus. (In addition to the two main fission fragments there are typically one or more free neutrons in the final state; in your analysis make the simplifying assumption that there are no free neutrons, just two daughter nuclei.)

Objects involved in the reaction:

Nucleus	# of protons	# of neutrons	Charge	Rest Mass (atomic mass units)
U-234	92	142	+92e	233.99
Pd-117	46	71	+46e	118.393

Although in most problems you solve in this course it is adequate to use values of constants rounded to 2 or 3 significant figures, **in this problem you must keep 6 significant figures throughout your calculation.** Problems involving mass changes require many significant figures because the changes in mass are small compared to the total mass. **In this problem you must use the following values of constants, accurate to 6 significant figures:**

Constant	Value to 6 significant figures
c (speed of light).....	2.99792×10^8 m/s
e (charge of a proton).....	1.60218×10^{-19} coulomb
atomic mass unit.....	1.66054×10^{-27} kg
$\frac{1}{4\pi\epsilon_0}$	8.98755×10^9 N·m ² /C ²

Fission Problem (continued)

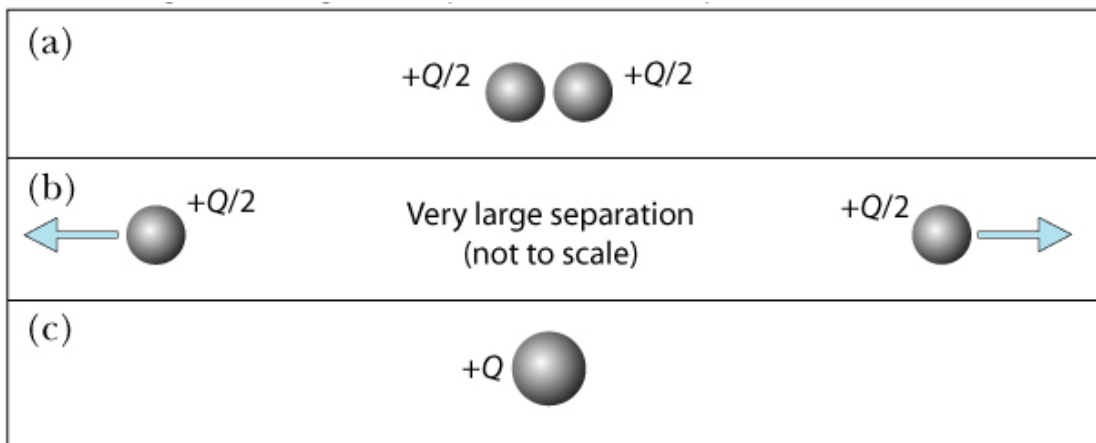
There are three states you should consider in your analysis:

- (1) The initial state of the U-234 nucleus, before it fissions.
- (2) The state just after fission, when the two palladium nuclei are close together, and momentarily at rest.
- (3) The state when the palladium nuclei are very far away from each other, traveling at high speed.

A: The final speed of the fission products

Your first task is to determine the final speed of each of the daughter nuclei in state (3), when they are far from each other.

Here is a diagram showing three important states in the process:



Fission Problem (continued)

Which diagram depicts the state of the original uranium nucleus? We'll take this state to be the initial state.

- a
- b
- c

Which diagram depicts the state when the two daughter nuclei have reached their final speeds? We'll take this state to be the final state.

- c
- b
- a

Compare the initial and final states of the system. Which quantities have changed?

- potential energy
- kinetic energy
- rest energy

What will be the total kinetic energy of the two daughter nuclei when they are very far apart?

$$K_1 + K_2 = \boxed{} \text{ joules}$$

Their initial state is the single nucleus, while their final state is the two daughter nuclei, far apart and moving away from each other. S1directs the construction of the solution and creates an Issue around how to set up the calculation to deal with all nuclei involved (AI - P). The diagram for the creation of this Issue can be found in Figure 5.22 next to the diagram for a typical Solution Approach Issue creation Figure 5.21.

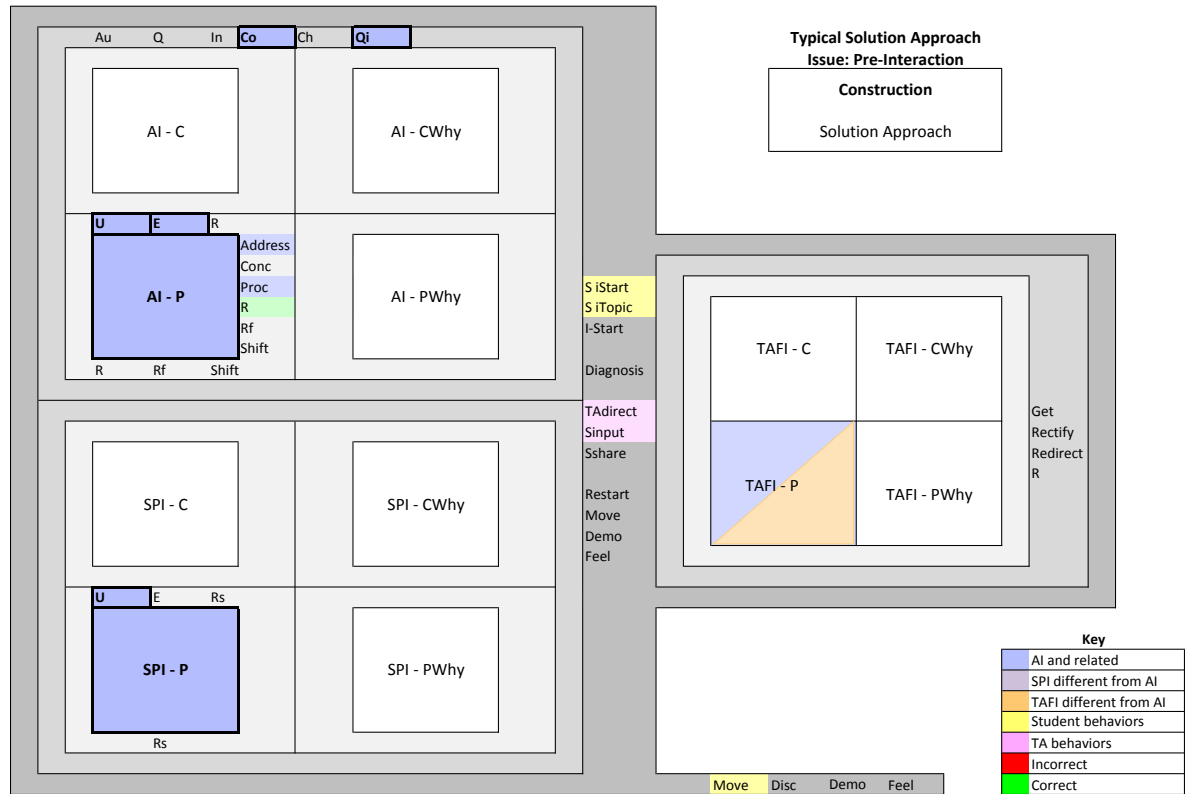


Figure 5.21: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present before the interaction begins. Other common features are muted.

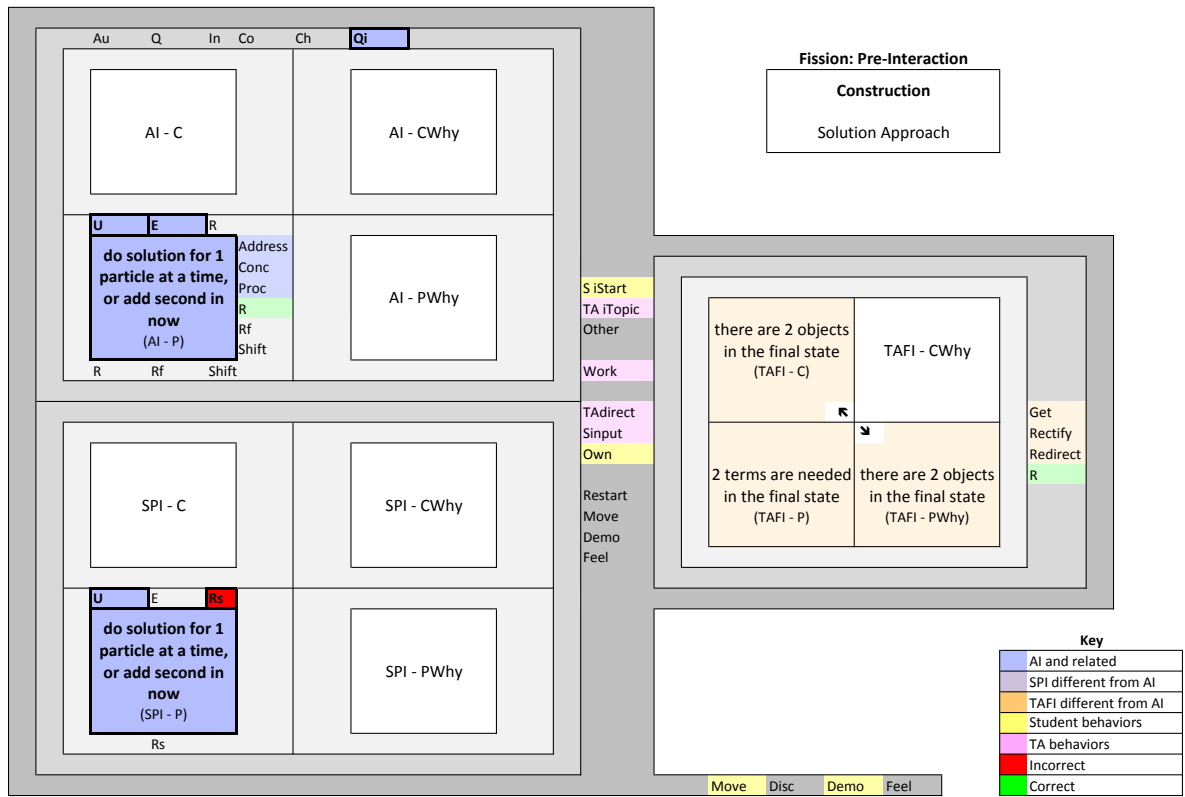


Figure 5.22: An example Issue diagram for a typical Solution Approach Issue from the Fission Lab. This diagram includes most features of the typical story (excluding Co) as well as many features unique to the example. Highlighted, bolded features are those present before the interaction begins. Other features are muted. AI - P, U, E, SPI - P, U, and Qi are present in the typical story as well. The two diagonal arrows indicate the C and PWhy components are identical.

The Issue is first brought up by S2, the recorder. He clarifies one of the steps S1 is giving him as he writes out the equation.

319 **S1:** So, and then this is kinetic energy. (pointing to the whiteboard)

320 **S2:** Of one of the (final) nuclei, right?

321 **S2:** Yeah, just one of them.

322 **S1:** K1

323 **S2:** Plus - yeah

324 **S1:** Plus U_1 (writing out on the whiteboard $K_1 + U_1$ for K_{final})

S1 initially creates the Procedural component of the Issue by confirming for S2 that their calculation will involve kinetic energy of just one of the daughter nuclei. S3 then asks a question concerning the calculation, and S1 further develops her strategy.

325 **S3:** Did you have plus K_2 for the second?

326 **S1:** I think you find each individual one and then add them... wouldn't you?

327 **S3:** Yeah, but would you add the K s?

328 **S1:** Like I'm saying, like do each individual calculation,

329 **S3:** Oh, uh

330 **S1:** and then add them at the end. Does that make sense?

331 **S2:** Right. yeah yeah yeah

332 **S1:** Like find the K final-

The creation of this Issue is fairly typical, though the continued clarifying by S1 and lack of Collaboration is not. S3 asks S1 to clarify what her plan is by asking about the detail of putting in a term for both particles' kinetic energy (Q_i) (line 325). This helps S1 reveal to the group the moves she is using to construct this solution (lines 326, 328, and 330). She plans to do two separate calculations, one for each particle (I assume daughter nucleus here) and then add them after each calculation is done. This is certainly Erroneous. The questions from S3 alert S1 to the idea that a group member does see a possible Issue forming, an Uncertainty with the setup. This is acknowledged with the presence of the SPI. This awareness of the Issue leads to S1 clarifying the procedural moves to be made, Resolving that SPI incorrectly, and confirming that the Procedural component of the AI does have an element of Error.

The group continues mapping out their solution, correcting certain terms, but still making moves toward doing the calculation for each particle separately.

During the Interaction

Once the students have mapped out their approach, they continue on with their solution con-

struction until this Issue is brought up during an interaction. The GTA, in fact, brings up this Issue and Addresses it as a second topic of discussion during an interaction (TAiTopic). The diagram for this section and its typical comparison can be seen in Figure 5.23 and Figure 5.24.

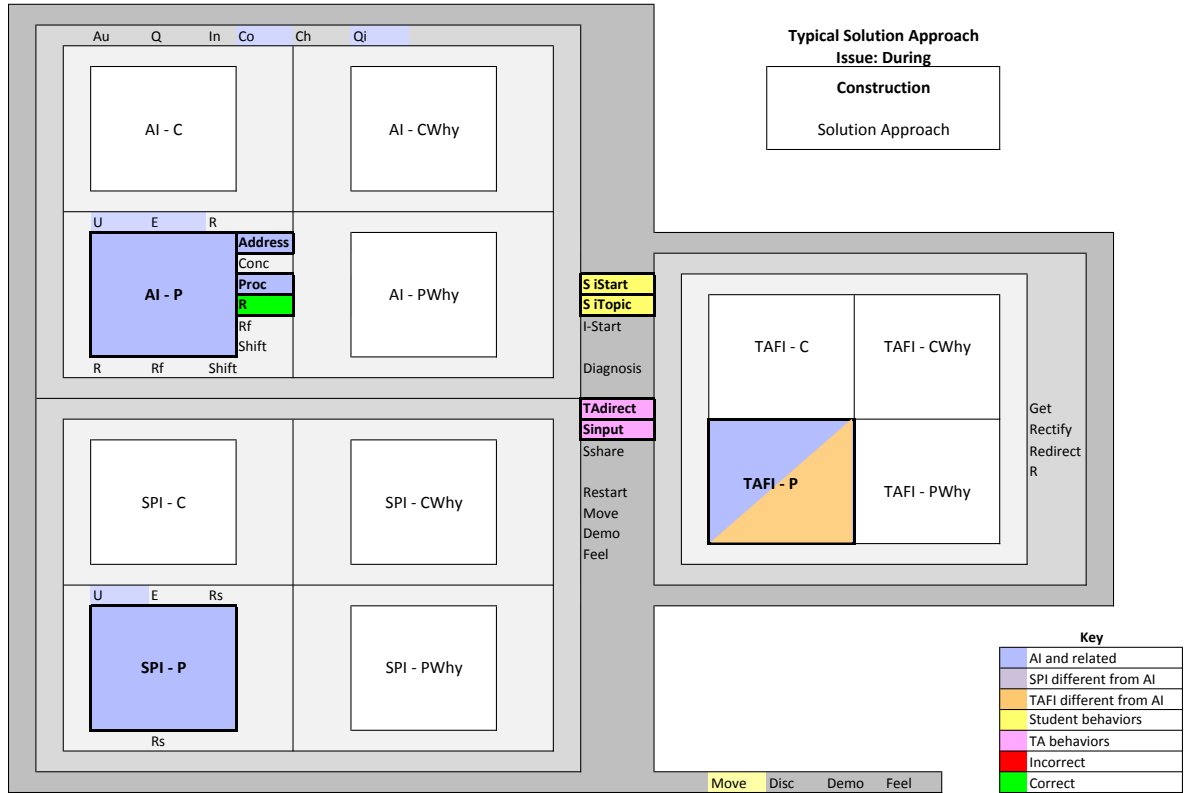


Figure 5.23: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present during the interaction. Other common features are muted.

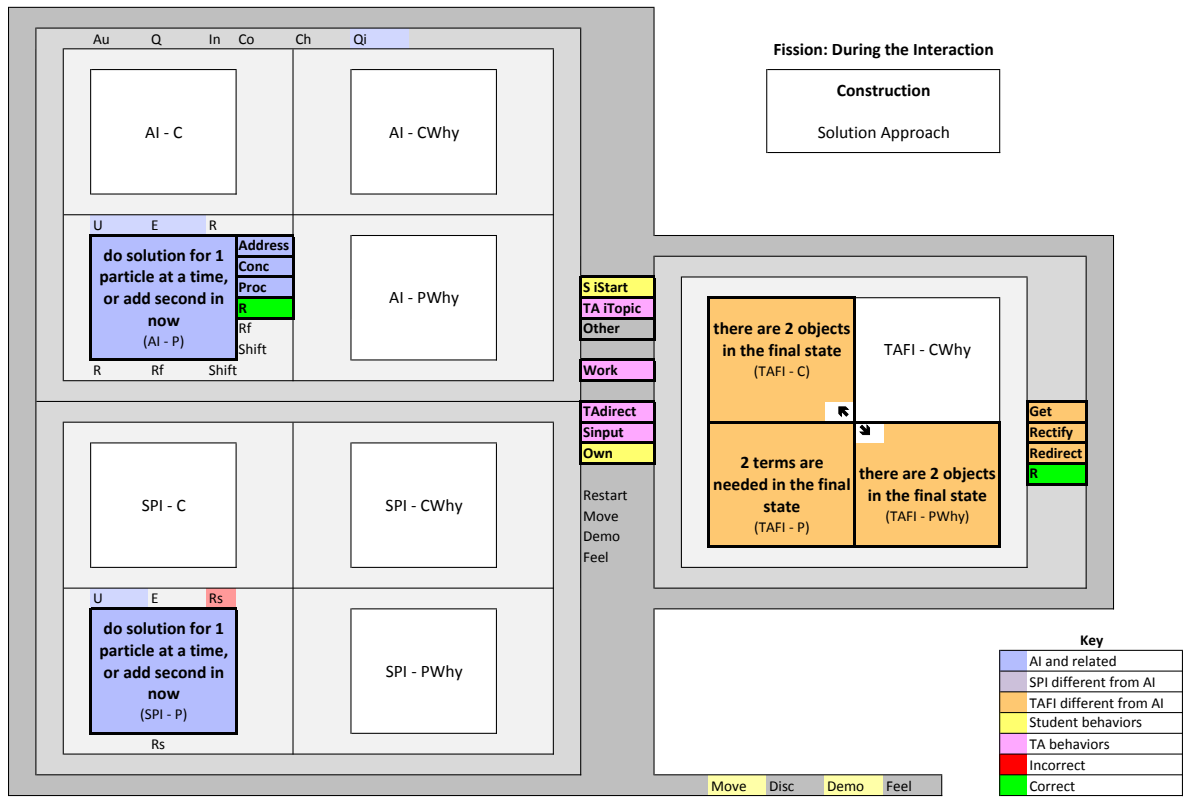


Figure 5.24: An example Issue diagram for a typical Solution Approach Issue from the Fission Lab. This diagram includes most features of the typical story as well as many features unique to the example. Highlighted, bolded features are those present during the interaction. Other features are muted. AI - P, Address, Proc, R, SPI - P, SiStart, TAdirect, TAFI - P, and Sinput are present in the typical story as well. The two diagonal arrows indicate the C and PWhy components are identical.

The yellow Own feature, multi-component, completely orange TAFI, and student responses to the TAFI stand out in the example diagram when compared to that of the typical story. The dialogue reveals that the Issue is Addressed a bit differently than it was created. The students' equation on the whiteboard preceding the beginning of this interaction reads: $mc^2 + K_f = K_i + U_i + mc_i^2$

333 **S1:** Okay. Now how do we find-

334 **GTA:** So now, so how many objects do you have in the final state?

335 **S3:** Two?

336 **GTA:** Ah. So we need-

337 **S1:** But, so we do have to calculate- okay, never mind - sorry, my fault

338 **GTA:** So this is for one object over here, (pointing to whiteboard initial terms)

339 **S1:** Yeah

340 **GTA:** in the initial state, that one, big old nucleus (gestures making a fist)

341 **S1:** Okay

342 **GTA:** Over here you've got two nuclei (pointing to whiteboard final term)

343 **GTA:** All right, so how many m c squareds do you need?

344 **S3:** Two.

345 **GTA:** How many K fs do you need?

346 **S3:** Two.

347 **S1:** Two.

348 **GTA:** Right.

349 **S1:** Sorry. That was my fault. I was thinking like you do it individually, but I guess you

350 don't.

351 **S2:** (writing out additional K_{f_2} term in the final state on the whiteboard)

First I note what is typical here. The GTA directs (TAdirect) the interaction. This begins when he cuts off S1 in the beginning and focuses the group attention around the topic of objects in the physical situation (line 334) and the terms needed in their equation (line 343 and 345). In doing this, the students' Issue is Addressed with Procedural talk as the GTA guides them to identify the need for additional terms in the equation of the final state. He questions the group to draw them through his line of reasoning (Sinput) (line 334, 343, and 345). Evidence that the AI has been Resolved during the interaction, indicating a change in procedural moves by the group, comes at the end by S1 as she identifies the Error in her thinking (line 349). She realizes that they must use one equation with all terms instead of two separate calculations.

The GTA's questions (Sinput) in this example request students give information about the

physical situation and equation (line 334, 343, and 345). This is different from the first example in that the questions do not act to only correct the students' original moves. However, similar to the previous example, all questions are targeted questions with only one correct response. Students ideas or overall thoughts on the terms in question are not asked about.

There are less typical features of interest here as well. One of the more notable features is the difference between the AI and the TAFI. The GTA focuses on the number of terms necessary in the students' equation, drawing on the number of objects in each state as reasoning. The implicit assumption here is that the students used this or a similar strategy in constructing their solution, and perhaps mis-counted their objects or misinterpreted something. However, as evidenced in the creation of the Issue, the students are aware that the initial state had one object, the final state two, and that all these objects needed their own terms. S1 attempted to apply a different solution strategy to deal with these objects. Thus, in focusing on the number of terms based on the number of objects, the GTA misses identifying the AI altogether.

Possibly because the scenarios for the students' procedural moves are either treating the particles separately or putting all terms together in one equation, the AI is still Addressed and Resolved through this different TAFI. S1 even acknowledges in the end, Rectifying her earlier idea with this new information, that she thought she could "do it individually, but I guess you don't" (line 349). I note here that she does not seem to know why her strategy is faulty but makes a mental note that it is and moves on.

Post-Interaction

After the interaction, the students' have most of their terms in place and Move forward with their solution construction, leaving this Issue behind. Figure 5.25 and Figure 5.26 shows the comparison between this diagram and the typical Solution Approach post-interaction diagram.

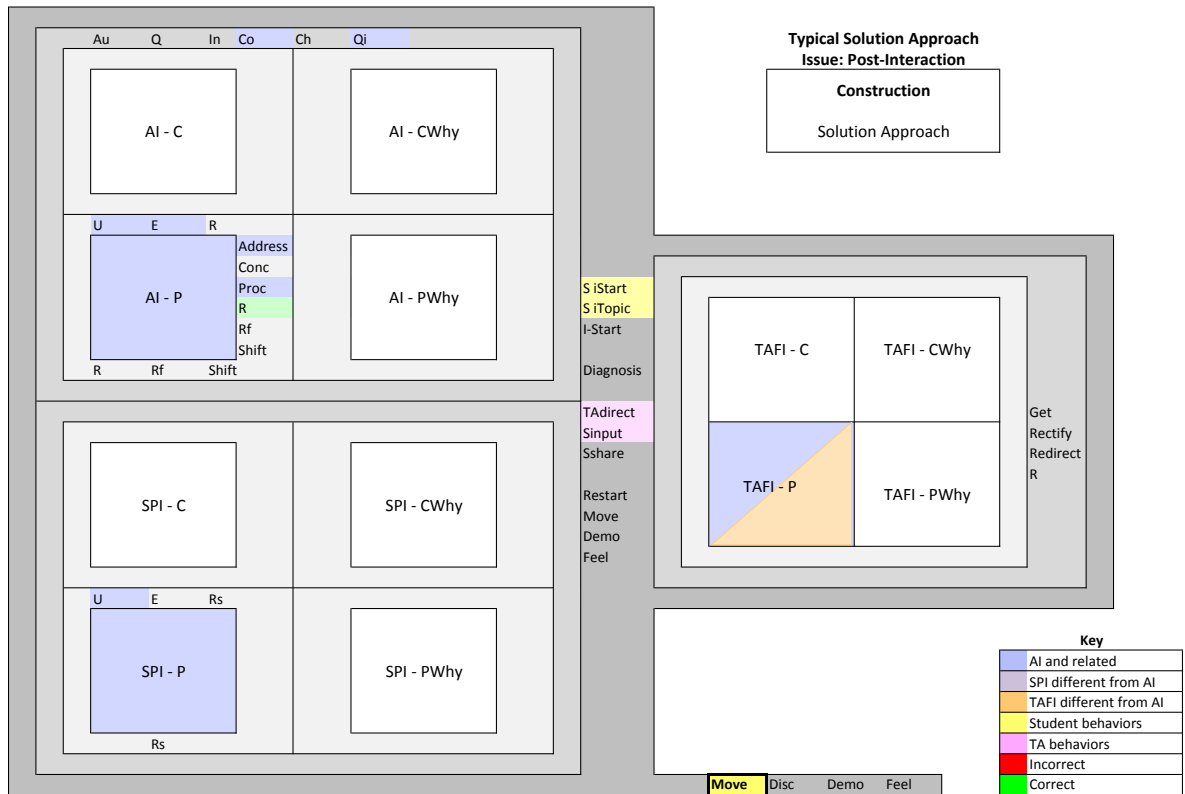


Figure 5.25: The Issue diagram for a typical Solution Approach Issue. Highlighted, bolded features are those present after the interaction. Other common features are muted.

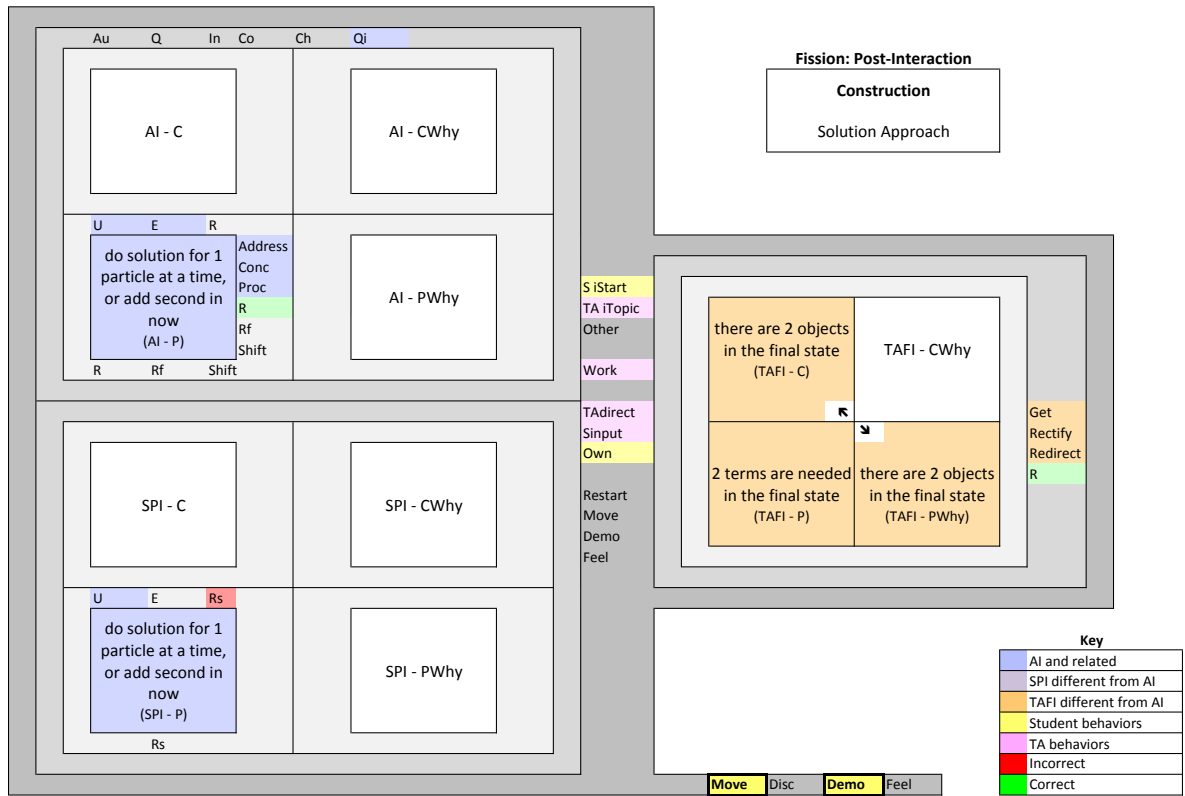


Figure 5.26: An example Issue diagram for a typical Solution Approach Issue from the Fission Lab. This diagram includes most features of the typical story as well as many features unique to the example. Highlighted, bolded features are those present after the interaction. Other features are muted. Move is present in the typical story as well. The two diagonal arrows indicate the C and PWhy components are identical.

Demo is also highlighted here as well as Move. The following excerpt will illuminate the Demonstration of understanding.

352 **S2:** (writing out $K_{f1} + mc_{f1}^2 + mc_{f2}^2 + K_{f1} = K_i + U_i + mc_i^2$)

353 **S3:** So then, you just bring the K Fs on one side, right, and everything else on the other
354 side?

S2 makes the correction that had been discussed (line 352). Since S2 initially assisted in the creation of the Issue but did not participate in the interaction, his understanding of the moves to make is Demonstrated through writing corrections on the whiteboard. After this, S3 begins Moving the group forward by further detailing their next mathematical moves in the problem (line 353).

Reflections on Solution Approach Example 2 - Fission

This Issue has a fairly common creation but a less typical interaction. It exemplifies that the typical features of this category do not tell a complete story. The complete story of this example includes an interaction in which the GTA encourages student input (Sinput) but focuses on a topic (TAFI) that does not match the AI. The TAFI does, however, Address the AI with both Conceptual and Procedural talk, painting a more complete story of the solution construction than the students did in creating the AI. In this case S1 Rectifies her original ideas using information from the TAFI by articulating that she realizes she went wrong in how she planned their strategy (line 349).

Before the interaction, The students' process is mapping out a procedure for the solution - specifically the order of calculating terms for each particle (AI - P, Qi). The procedure is Erroneous, but the students continue with it. During the interaction, the students' process changes to one of participating in a description of the physical situation and how it relates to the procedure that *should* be followed (TAFI - PWhy/C, TAFI - C, Sinput). The process continues to change during the interaction to one of Rectifying what was incorrect in the original procedure to what should be done going forward (Rectify, AI - Resolution, TAFI - Resolution).

After the interaction, the students' process works to remap the procedure for the solution and continue working with the corrected procedure (Move, Demo). The interaction is situated in this process to correct students Error (AI - P - Resolution, Rectify, Own).

Since the TAFI does not match the AI - P the students initially created, the interaction being situated to influence a Resolution of the AI - P is not supported by the TAFI - PWhy/C or TAFI - P. The GTA focuses on the Issue of the presence of energy terms for only one particle, missing how the students discussed the process before the interaction. It is S1's realization of the correction being made that situates the interaction in the students' process of correcting their procedural move. These are revealed in the Rectify and Own features. The TAFI - PWhy/C and TAFI - P serve to model the appropriate content ideas that lead to appropriate procedural moves, but miss matching the students' process here, even as they correct the procedure.

Because of the variation between the examples in the typical story and even between these two examples, I find it most useful to turn the reflection toward the features that make up some of the variations in Issues within this category.

Reflections on the Typical Solution Approach Issue

As seen above, each Issue is quite unique when compared to the typical story and to other Issues in this category. What makes these Issues unique is that the features that are less common are still present in quite a few Issues. I'll review some of these features below. I start with a discussion of multi-component Issues. I'll then continue by reviewing where the TAFI and AI do not match (TAFI Mismatches) and diagnoses. Finally, I discuss the encouragement of students' input (Sinput). While Sinput is typical, the variations seen in the two examples above and the lack of encouragement of sharing ideas (Prompt) warrant discussion.

Multi-component Issues

There are more non-P AI components (PWhy, C, CWhy) in the Solution Approach Cate-

gory than in the other categories combined.¹⁷ This shows that students are constructing more complete Issues in this category than others. They express more reasoning along with their procedural moves, or separate from their moves, in this category than they do in others. Why this occurs is not the focus of this research, but I can speculate that this might be due to there being more content and reasoning required in this part of the problem in order to get through the problem. Solution Approach encompasses the more complex pieces of the problem solution, those of constructing the appropriate terms. In attempting to do this, students add in more reasons for doing so and construct more Issues dealing with physics content and the physical situation. As seen in the first example, when Challenged, S1 adds on a full argument of physics content reasoning behind attempting to figure out whether or not work should be zero. In identifying these kinds of arguments and explanations throughout the data, I found that most of them appeared before students executed their solution calculations. Thus, the most discussion of physics content by students is done so in the Solution Approach category.¹⁸

TAFI Mismatches

I was surprised by the kinds and amount of mismatches I saw between the TAFI and AI in this category. Mismatches indicate that physics content or procedural moves present in the students' expressions and actions before the interaction may have not been focused on during the interaction. It also means physics content and procedural moves *not* present before the interaction may have been added during the interaction.

Half of the TAFIs matched the AI completely.¹⁹ Most of the TAFIs matched the AI in at least one of the components, but there were mismatches due to addition, absence, or Issue content differences in half of the Issues in this category. In the previous category, Getting Started, TAFI mismatches came from the GTA adding in additional physics content or procedural

¹⁷Even though these components are not common enough to warrant an appearance in the typical story, they are most common to this category over any other category.

¹⁸The TAFI contains multiple components more often in general, but still only contains them in 10 of the 23 Solution Approach Issues.

¹⁹All of the 12 Issues in this category with TAFI mismatches occurred under two of the four GTAs (GTA 2 and GTA 4).

information to build a more complete picture that was not present at all for the students before the interaction. In this category, there is a mixture of (1) TAFIs that miss physics content present in the AI before the interaction, as in the first example above; (2) TAFIs that add in physics content to form a more complete story, similar to the Getting Started Atypical Case; *and* (3) TAFIs that focus partially, if not wholly, on a different Issue, as in the second example above. This range of TAFI mismatches was unexpected, and so I reflect on each of these cases below.

First, there are Issues in which the TAFI is different for having left out components that were present for the students before the interaction. This indicates that the GTAs are not pulling as complete a story from the students as is present beforehand. Again, I can return to the first example in this section as the GTA focuses only on the P component of the students' Issue, despite S1 crafting a complete argument before the interaction. In that case, the students never returned to discuss or Resolve those components after the interaction, indicating it was important to focus on them during the interaction.

Second, there are Issues in which the TAFI adds on physics content. This typically occurs only with the most experienced GTA, and is also evidenced in the second example above in which the GTA adds in reasoning about the physical situation to support the addition of further terms in the solution. The addition of components then seems to build scaffolding into the discussion of an Issue, creating a more complete story of the situation than was present before the interaction. If there are benefits or detriments to the students due to this addition, they are not pulled out in the framework.

Finally, there are Issues in which the TAFI contents are different from the AI contents. This indicates that the procedural moves and physics content the GTA is focused on during the interaction are different than those the students are focused on before the interaction. This is evidenced in the second example in which the GTA focuses on the specific number of terms in the equation rather than on the strategy of how to construct the equations to account for both particles. In this case, S1 is able to Rectify her idea with this different TAFI. However,

in the complex example in Chapter 4 (beginning on line 88), there is a different story of the students finding the interaction to be unhelpful to what they were struggling with. This indicates a range of possible responses from students to these mismatched TAFIs, both positive and negative.

The framework does not specifically pull out the overall affect of a mismatched TAFI on the students. That is, none of the features surrounding the interaction differ dramatically in response to a mismatched TAFI. Future research will need to examine the possible effects of mismatched TAFIs. I see two possible feature combinations that may offer direction for future research.

First, the Issues without full Resolutions in this category only occur alongside TAFIs in which more than one component is different (six Issues) from the AI.²⁰ Second is the distribution of the Work diagnosis. Table 5.1 shows these results. The Work diagnosis is present in four of the six Issues that have two or more mismatched TAFI components.²¹ For comparison, Work appears in just three of the 16 Issues with zero or only one mismatched TAFI component. Due to the small numbers here, I can not know if there is a real effect. But I do think there is enough of a pattern in this feature to include it in further research on mismatched TAFIs in this category.

Many of the TAFIs match the AIs in at least one component. However, the kind of mismatches seen and the quantity were surprising as I expected the GTAs to consistently identify the full AI and focus on it. While it appears that the GTA adds in physics content in some cases, in others AI components are left out or a different topic is focused on altogether. In the latter instances, I see a possible connection to the Work and Resolution feature. These two areas need to be further explored in future research.

²⁰This excepts the second example above, in which the AI was fully Resolved. As can be seen, however, from that interaction, it took S1 having a full realization of the connection between her original actions and the GTA's help to achieve that Resolution. Its absence in other similar cases is not surprising.

²¹The Work diagnosis only occurs six times total, and is present three times in the four Issues in which more than one TAFI component is mismatched. This is because one interaction was repeated for two Issues in which the diagnosis came from the exact same dialogue, making it a repeat, rather than a unique diagnosis.

Diagnoses

One feature that stood out for its complete absence in this category was Active diagnosis. Instead there is a distribution of the other three kinds of diagnoses (Listen, Work, Abbreviated).²²

Active diagnosis is the kind of diagnosis that encourages the most student participation in the diagnosis part of the interaction. A lack of Active diagnosis implies that the GTA is not probing students to further explain themselves and their ideas to identify the Issues. I would expect that the GTA needs to use a more Active diagnosis due to the greater complexity of Issues in this category (as seen through greater presence of multi-component AIs). While it is unclear why Active diagnosis is not used in this category, I turn to the remaining kinds of diagnoses to see how well they help the GTAs match the AI. I look for TAFIs that match the AI in at least one component and do not leave out any AI components. I'll call diagnoses that help GTAs make this match "adequate" diagnoses. In inadequate diagnoses the TAFI does not match the AI at all or there are AI components left out of the TAFI. These TAFIs are the ones in which the GTA either misses certain pieces of the AI or focuses on a different topic altogether.

Due to the kinds of diagnoses being ranked, the comparison is made among only the top level diagnoses used in each data segment. It is possible that a GTA uses a lower level diagnosis, is unsuccessful at reaching a desired TAFI, and then moves up to a higher level diagnosis. Cases like these are not pulled out by the framework but would indicate that certain diagnoses are in fact not adequate. However, they are vetted by the GTA rather than the researcher. I did not examine the data rigorously for these cases, but I did explore it further to see if I could identify any instances with a cursory examination. I found one case in which a GTA seems to "level up" the diagnosis type after a lower level diagnosis is not fruitful. This case was with an Execution Issue. I found no cases of it in Solution Approach Issues. In these Issue, uses of multiple diagnoses, when they occurred, seemed to be more concurrent rather than ordered. However, this assessment is merely speculative as I did not fully analyze the data for the multiple

²²All Active diagnoses show up in Execution Issues.

Table 5.1: All Solution Approach Issues sorted by diagnosis and by the number of AI components mismatched with their respective TAFI components. *See footnote 24

TAFI Mismatches				
Diagnosis Type	0 mismatches	1 mismatch	2+ mismatches	
Active	0	0	0	0
Work	2	1	4	7
Listen	3	1	2	6
Abbreviated	6	3	1*	10
	11	5	6	

kinds of and order of diagnoses.

Table 5.1 shows the breakdown of the results.²³ I mentioned the Work diagnosis in the section above but repeat it here briefly too. The Work diagnosis appears in seven Issues (but with six unique diagnoses). The Listen diagnosis is present in six Issues. Four of these are Issues in which the TAFI and AI match in at least one component and do not leave any out. The Abbreviated diagnosis is present in 10 Issues. Nine of these are Issues in which the TAFI and AI match in at least one component and do not leave any out. While the tenth is a complete mismatch, it is also an exceptional case and will be disregarded in further discussion of the results.²⁴

This indicates that the Abbreviated diagnosis seems to be the most adequate of the three at leading to a TAFI matching at least one AI component. The Work diagnosis seems to be least adequate, with the Listen diagnosis in the middle. I recognize again here that there is a very small sample size, and so I pull out the numbers simply to identify the beginnings of a possible pattern. This pattern reveals that the Work and Listen diagnoses may not always give the GTA the appropriate information on the AI.

²³I have broken down the results further by identifying those TAFIs that form complete matches with the AI and those that have a mismatch in any component as well.

²⁴In the tenth Issue, the students had asked the GTA about a different WebAssign problem than the present one of that data segment. Discussion about that problem indirectly Addressed their current Issue, and so the dialogue was included in the present data segment. Thus, by definition (rather than by the GTA's choice), the TAFI mismatched the AI, making it an exceptional case.

It is interesting, however, that the Abbreviated diagnosis does help the GTA match the AI. Since Abbreviated diagnoses by definition are those in which very little information on the Issue is exchanged, I would expect them to be inadequate at leading to a match in this category. And I would expect Active diagnoses to be *necessary* to lead to a match. I don't see that, however, and there are no Active diagnoses for comparison. However, reviewing the diagnoses across all multi-component AIs shows that, regardless of the diagnosis, the TAFI matches the AI in more than one component only once.²⁵ That case is one in which the students ask the GTA to confirm their multi-component AI, and he does. This result shows evidence that none of the three diagnoses are necessarily adequate for fully matching the AI, even as Abbreviated *is* adequate at matching a single component. I discuss this more below when I compare the diagnoses across all categories in Section 5.5.3.

Sinput

Sinput is only present as a common feature in this Solution Approach category with 14 of 22 instances of Sinput occurring here. Additionally, four of five GTAs use Sinput only in this category of Issues. I discuss these distinctions among GTAs more thoroughly in Section 5.6.

Most often, Sinput took the form of very targeted questions with one correct answer. Rarely did I see probing questions for students ideas (indicated by the additional Prompt feature). The Sinput (and Prompt) features cover the presence of *any* instance of encouragement of student participation by the GTA. It does not cover how often or how continuously that encouragement is used throughout the interaction. The second example above shows multiple targeted questions strung throughout the interaction to lead the students through the reasoning (lines 254, 268, and 280 - 284). The first example only has one targeted question (line 310), and as seen, its purpose is to correct rather than to discuss. This indicates that the Sinput feature falls short of really revealing more about the interaction itself and how much students are encouraged to participate. This feature will need to be expanded on in future research. I discuss this limitation

²⁵There is an even distribution of the three kinds of diagnoses across the multi-component AI data segments.

more in Section 5.7.

5.2.4 Solution Approach: An Atypical Case

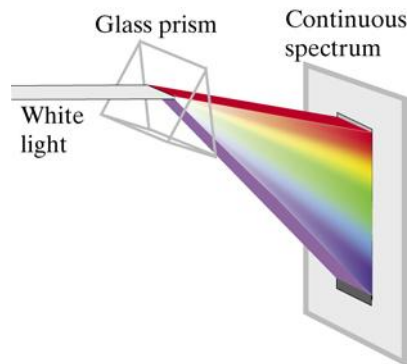
Finally, I examine a case that contains very few typical features. I do this for comparison and to show the range of different Issues in this category. In this case, students are tasked with finding all energy jumps in hydrogen that produce photons in the visible range of light. The full problem statement can be found in Figure 5.27.

Figure 5.27: Spectra problem statement

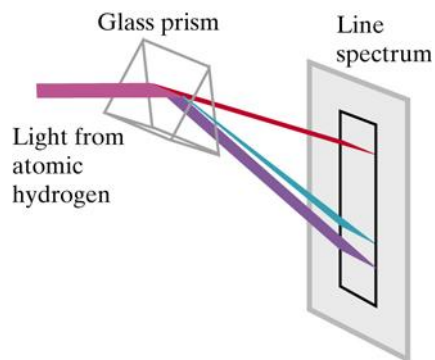
Spectra Problem 1

The average eye is sensitive to photons with energies in the range from 1.8 eV, corresponding to red light, to 3.1 eV, corresponding to violet light. White light is a mixture of all the energies in the visible region.

If you shine white light through a slit onto a glass prism, you can produce a rainbow spectrum on a screen, because the prism bends different colors of light by different amounts.



If you replace the source of white light with an electric-discharge lamp containing excited atomic hydrogen, you will see only a few lines in the spectrum, rather than a continuous rainbow.



The energies of the quantized states in atomic hydrogen are given by $E_N = -\frac{13.6}{N^2}$ eV, where $N = 1, 2, 3, \dots$

Spectra Problem 1 (continued)

Given this, predict how many lines will be seen in the visible spectrum of atomic hydrogen, and specify the atomic transitions that are responsible for these lines.

Fill in the following table, listing the energies of the visible photons emitted in order, from highest to lowest energy. Put zeroes in any remaining boxes.

N of initial state	N of final state	Photon energy
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV

The students are working out the basic picture in this problem by attempting to reconstruct the energy diagram for hydrogen. Figure 5.29 and Figure 5.28 show the diagram for this Issue next to the typical story.

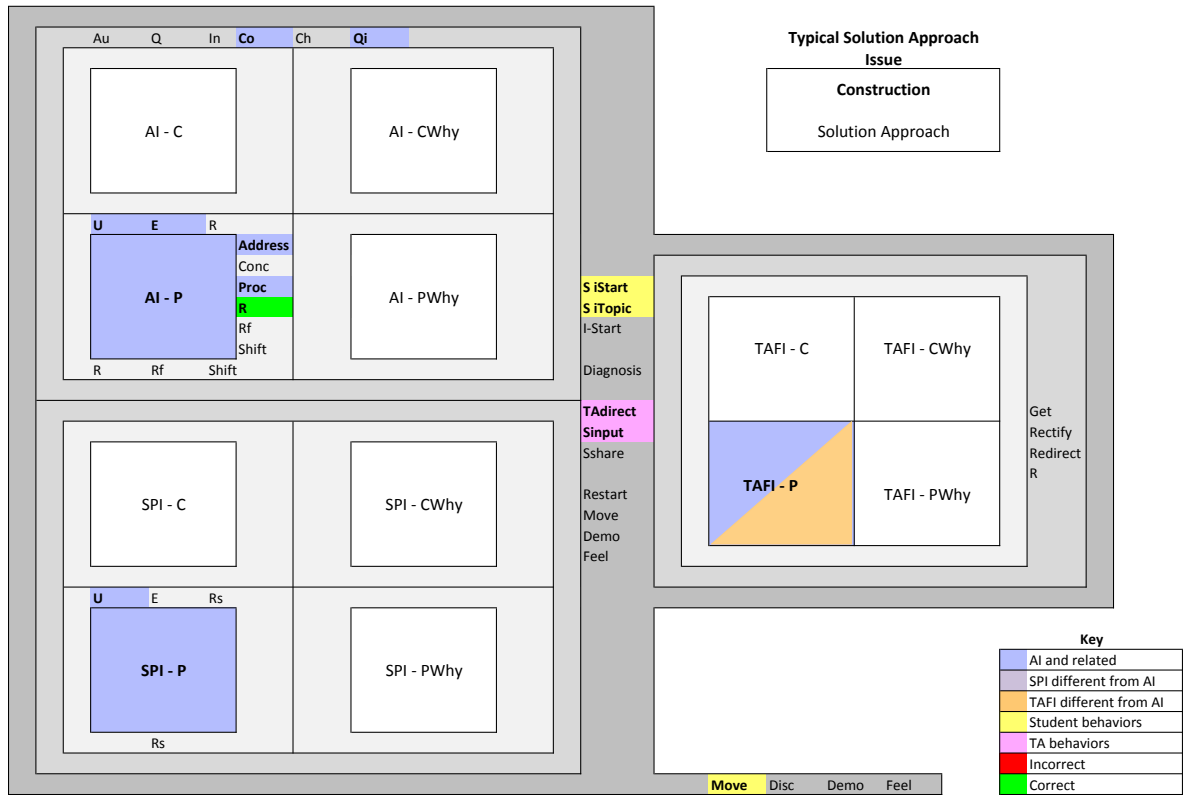


Figure 5.28: The Issue diagram for a typical Solution Approach Issue. Features that are present in at least 15 of 23 Issues are highlighted. The TAFI - P is colored both orange and blue as neither was dominant.

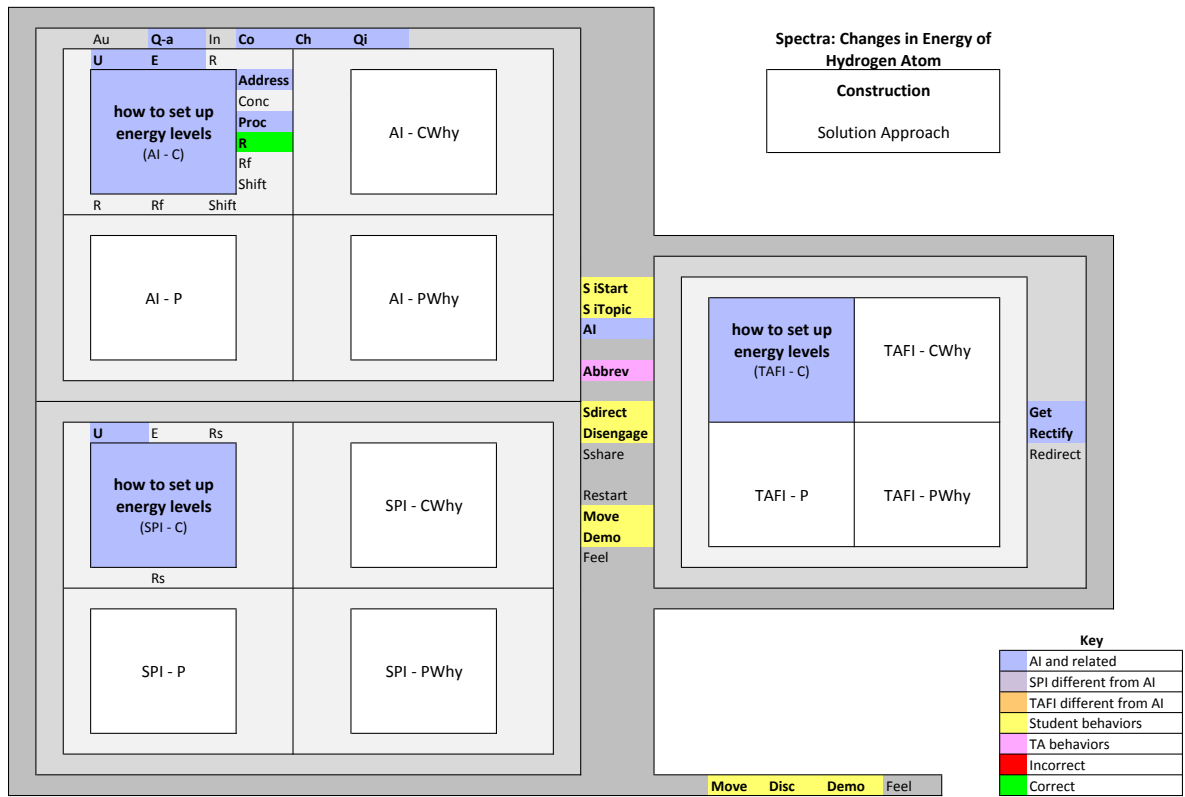


Figure 5.29: An example Issue diagram showing an atypical Solution Approach Issue from the Spectra Lab Problem 1. This diagram contains only *some* features present in the typical story (AI, E, U, SPI, U, Co, Qi, Address, Proc, R, SiStart, SiTopic, TAFI, and Move). (While the E, U, Address, Procedural talk, R, and TAFI features do exist in the typical story, I note that the features in this example concern the AI - C component, which is atypical.) The remaining features are unique to the example. All features present are highlighted.

Several features jump out as different from the typical story when comparing these diagrams including the Conceptual only AI and the middle column of yellow, student focused, features. I will discuss them upon reviewing the dialogue. The Issue is begun by S3.

355 **S3:** What's our ground state?

356 **S1:** One.

357 **S2:** Zero.

358 **S3:** Zero, right?

359 **S3:** No. Zero is the highest it can go. (drawing finger across to the top of the whiteboard)

360 **S2:** Oh yeah. That's right.

361 **S3:** So you need to know what the-

362 **S1:** High at seven,

363 **S3:** Seven?

364 **S1:** No, that one says one two three zero, aaahaaaah!

365 **S3:** It goes one, then two, then three, four, and it keeps going until- (drawing lines for the

366 energy levels as can be seen in Figure 5.30)

367 **S1:** Right, and that remains zero. (pointing to the first bottom line on the diagram)

368 **S2:** No. Zero's up there.

369 **S3:** No. Zero's up here. (simultaneously w/S2)

370 **S2:** These are all, they're sort of negative in a way. But that's zero.

371 **S3:** See, this is the ground state (writing "ground" next to to the first bottom line on the

372 diagram)

373 **S3:** (writes out number labels on diagram: 1, 2, 3, 4 as seen in Figure 5.30 and then raises

374 hand to ask the GTA)

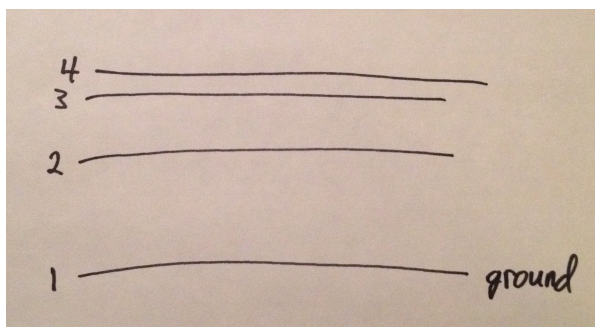


Figure 5.30: Students' whiteboard work shows S3's drawing of the energy levels of a hydrogen atom. The ground state is labeled "ground." To the left of the lines, the levels are number accordingly, "1," "2," "3," "4." The diagram is redrawn by the author for clarity.

Three features stand out as atypical in the creation of this Issue: (1) presence of only an AI - C component; (2) generating the Issue with a Question; and (3) presence of Challenge.

In this particular Issue, there is no Procedural component at all. S3 begins the Issue by asking about the ground state. Students Challenge each other, debating the general picture of the energy levels and where the ground state is, all expressions of conceptual physics content (lines 359, and 364 - 369). S2 and S3 seem to Collaborate, reinforcing each other's ideas that zero is at the top (lines 359 - 360), and the ground state, whatever that is, is at the bottom (line 371). S1's ideas get Challenged by both S2 and S3 as they attempt to remember what the details are. The Challenges and attempted clarifications lead S3 to draw a diagram to further explain his idea, providing more information about the content (line 365). There is also some Uncertainty as the students correct themselves and each other, refining their picture. Finally there is Error in S1's statement that the high is at seven and zero is the bottom (line 362 and 367).²⁶

S3 decides to check his ideas of how the energy levels look with the GTA.

375 **S3:** Yeah, okay so, yeah. So this is negative thirteen point six right? One? (labeling the
376 diagram²⁷)

377 **GTA:** Yeah. Th-this is up- yes.

378 **S3:** And then two is- what's negative 13.6 divided by four?

379 **GTA:** Yes, and do over nine. Do over sixteen.

380 **S3:** Yeah.

381 **S1:** negative three point four

382 **S3:** Negative what?

²⁶It seems that an underlying Issue of miscommunication exists, possibly responsible for the confusion students seem to share for each other's ideas. For instance, identifying zero as the ground state initially leaves me uncertain as to whether the students are numbering states, or identifying energy values. When S3 changes his notion to "zero is the highest..." it seems he is identifying the potential energy value (within the range -13.6 to 0), not the energy level label. S1's notion that zero is the bottom with a high at seven leads me to think she is numbering the levels (even if zero is incorrect), rather than talking about their values. This leaves confusion in the group as to what element is being discussed. S3 clarifies this better when he draws out a correct diagram. I don't think, however, that there is quite enough evidence from what the students express to completely describe this Issue as one of miscommunication about the energy levels.

²⁷The overhead video froze here, so there is no image of the diagram labelled.

383 **S1:** three point four

384 **GTA:** Yeah. And this model to find

385 **S3:** And then divided by nine (labeling diagram)

386 **GTA:** the possible difference between those energy states which can be

387 **S1:** Negative one point five.

388 **GTA:** within, that range, that is there without.

389 **S3:** And then divided by sixteen for four.

S3 has the GTA watch him identify the correct ground state and correct energy (line 375). It is here that S3 shows he does in fact have the fully correct idea of both where the ground state is and what the energy of that state is. Only his correct diagram was visible before, but not specifically whether he had the correct energies associated with it. This is clearly communicated to the GTA with “- 13.6” in line 375. The GTA confirms this idea (line 377), matching the AI, and adds on to it further energy levels (line 379).

However, right after the confirmation from the GTA (line 377), the students stop paying attention to him and Direct the rest of the interaction by Disengaging.²⁸ The GTA keeps an eye on what the students do and continues telling them what to do to construct the diagram (line 379 384, 386, and 388). But once the confirmation is given, S3 disengages from the interactions and asks S1 about the calculations for several subsequent energy levels, adding on to his original diagram (line 385). Through their disengagement and continued development of the diagram, S3 shows his full understanding of the physics content involved in creating the energy level diagram. S1 obliges, and poses no further debate suggesting the possibility that she too at least accepts, if not understands, the energy level setup at this point.

The Issue is Addressed with Procedural talk after it is brought up since the GTA describes what to do and the students calculate out the different levels to build their diagram. The Issue is clearly Resolved during the interaction, showing the students have confirmed a correct view

²⁸This is not as clear from the transcript but is clear in the video. S3 refocuses on drawing the diagram and getting it labeled.

of the energy level diagram as compared to before the interaction²⁹ (line 375) and Move forward to construct it. In so doing, they also Demonstrate that they understand the bigger picture of what the energy levels look like. After the interaction, the students continue Moving forward in accordance with the typical story.

Reflections on Solution Approach Atypical Example

This example shows a case in which students are grappling with how to draw and describe the energy level diagram for hydrogen. They exemplify this in their debate over what the ground state is. I show this example to contrast the typical story with one that lacks many of the common features of Solution Approach Issues.

This example is unique from the beginning as the students create an Issue in the C component only, and not around any procedural moves required by the problem. The students then seem to only want to check an idea with the GTA, rather than work through an idea more thoroughly. Once they have that confirmation, they ignore further checks and instructions by the GTA.

When I compare the interaction to the pre-interaction dialogue, I notice that the students use the interaction to identify the correct idea, but they do not discuss if and how other ideas were misguided. While I notice this contrast in the data, it is not something that would be highlighted in the framework. Though the combination of Disengage and Rectify may allude to it, I do not have enough examples to examine this further. However, it raises the question of what might have differed in a GTA directed interaction focused on illuminating all group members' ideas.

The students' process is one of figuring out, via debate, the physical representations and identifying the correct physics content needed to go forward with a solution (AI - C, Challenge, Uncertainty). The students' process changes during the interaction to focus on assessing one person's idea (SiTopic, Sdirect, Procedural talk, Rectify). It then further changes to continue

²⁹Since this Issue was created by all students together, I look for a general group consensus to establish that it was Resolved. I do not look to specific expressions of understanding by every single group member.

mapping out that one idea (AI - C - Resolution, Disengage, Move, Demonstrate). The process after the interaction shows a continuation of that idea leading to a fuller representation of the physical model (Move, Discuss, Demonstrate). The interaction is situated to focus and confirm the idea (AI - C - Resolution, TAFI - C).

How the interaction is situated can be learned mostly by the features pertaining to the students' direction of the interaction - Sdirect and Disengage - combined with their response to the TAFI - Get and Rectify. They control the interaction to Rectify an idea. They then no longer need the interaction, even though the GTA keeps talking, so they Disengage. Thus, the interaction simply serves to verify the idea. But in doing that, the interaction allows students' to focus their process and Move on with constructing their representation.

5.3 Execution Issues

In the next section, I'll move away from Issues concerning the construction of a solution and into Issues concerning the execution of a solution. Once a solution has been largely constructed, students begin to execute specific pieces of that solution. Execution comes in the form of finding numbers to plug into quantities, calculating answers, and converting any necessary units. I'll spend time exploring these Issues as well as the opportunities interactions provide for this part of the students' process.

5.3.1 Unit Conversions (8 Issues): The Typical Story

Unit conversions take up over half of all Execution Issues. Unit conversion Issues are just that - Issues students create around converting (or often not converting) a quantity's units. Like the previous sections, I examine the common story that runs through Issues of unit conversions.

The story of unit conversions typically starts with students making an Error in a procedural move by using a quantity of inappropriate units in their solution. They don't know they have done this, or at least don't realize it at the time, and carry on their solution until this Error is brought up in an interaction. During the interaction, students check their final answer, and

the GTA typically identifies the students' Actual Issue. They fix their mistake, making the procedural move of converting units they'd missed before the interaction. Often the correction of their mistake begins in the interaction and continues afterward. Once finished, students Move on in their solution construction. The diagram for this typical scenario is given in Figure 5.31.

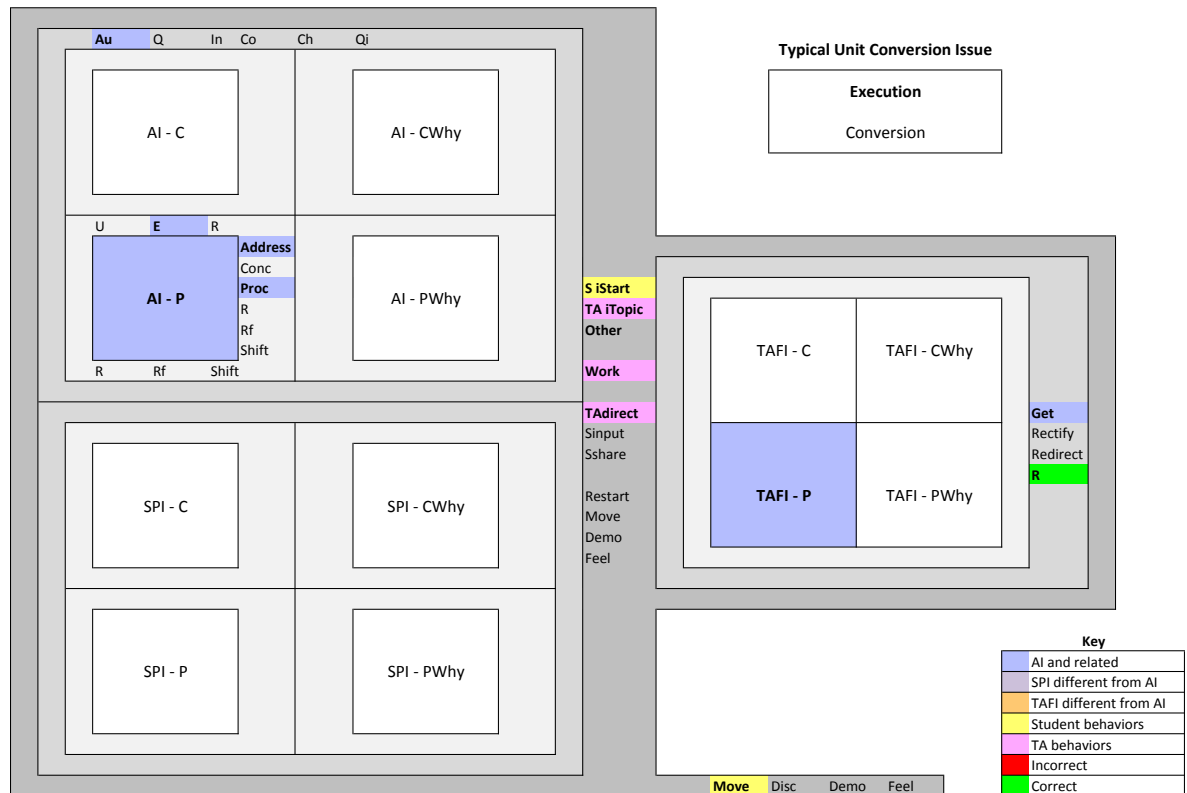


Figure 5.31: The Issue diagram for a typical Unit Conversion Issue. Features that are present in at least six of eight Issues are highlighted. I make an exception for the Work feature here which is present in four of six unique diagnoses. This is further explained in the section covering During the Interaction.

This category is similar to that of Getting Started in that the common features do in fact represent a fairly complete story of Unit Conversion Issues. I discuss this similarity further in Section 5.5.1. Now, I will discuss the details of the typical Unit Conversion story a bit more by

examining the pre, during, and post interaction pieces.

Pre-Interaction Creation of the Issues

Typically, students create Issues around unit conversions Automatically. That is, they select the quantity they need to use in their calculation and use it without performing at least one necessary unit conversion or discussing that unit at all. In so doing, the Issue created has only a Procedural component to it, and that Issue component is characterized by Error. Figure 5.32 shows the diagram for this.

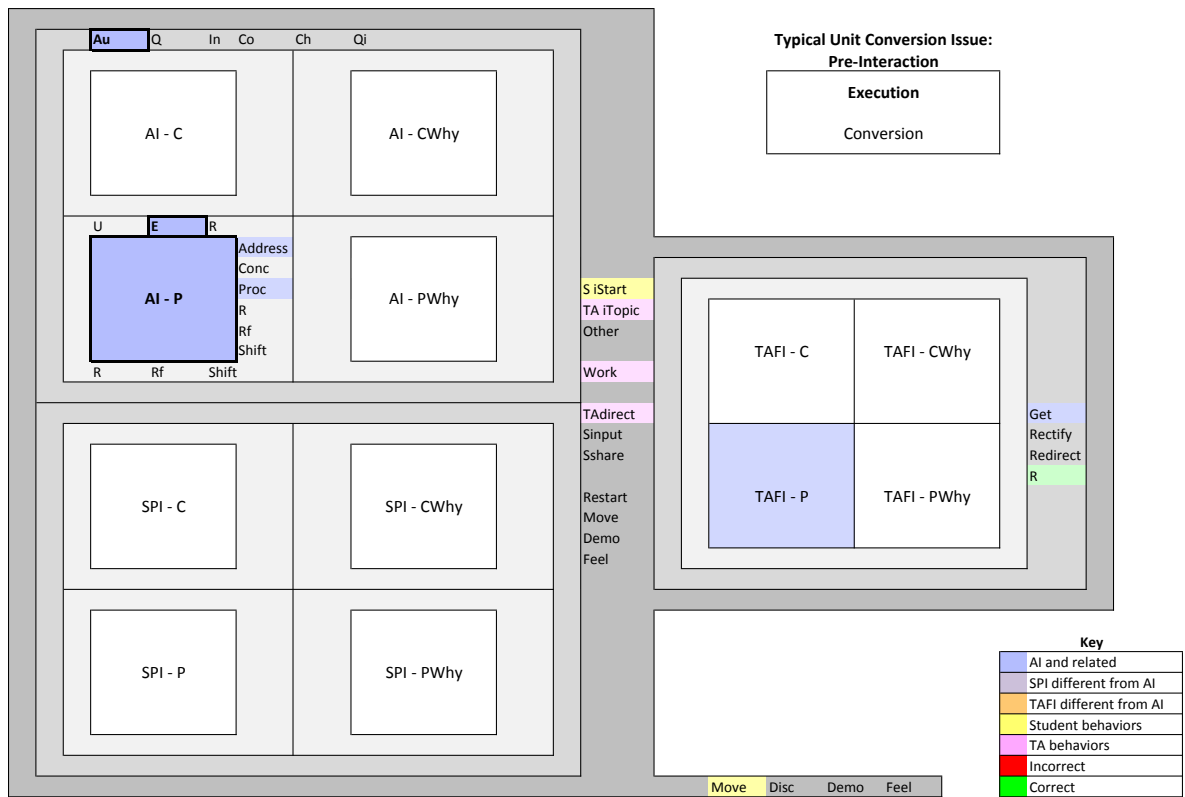


Figure 5.32: The Issue diagram for a typical Unit Conversion Issue. Highlighted, bolded features are those present before the interaction begins. Other common features are muted.

The following example segment is representative of this kind of creation. The full Issue

diagram for this example can be seen in Figure 5.34. Students are constructing a solution to find the ΔE of a nitrogen molecule (problem statement shown in Figure 5.7) given by,

$$\Delta E = \hbar\omega$$

where

$$\omega = \sqrt{k_s/m}$$

m is the mass of one nitrogen molecule in kilograms, and the students are attempting to calculate that value as they create the Issue.

390 **S2:** Fourteen (writing mass). That's gonna be - that's gonna give us the mass of two- Do
391 that (writing out calculation) calculation will give us the mass of two nitrogen, yeah

392 **S3:** (begins calculation on his calculator)

393 **S2:** You multiply it times two

394 **S3:** (continues calculation on his calculator)

395 **S2:** Ahright, what value is it? (looks at calculator) four point six-

396 **S3:** six five one nine (4.6519) times - er - times ten to the negative twenty three

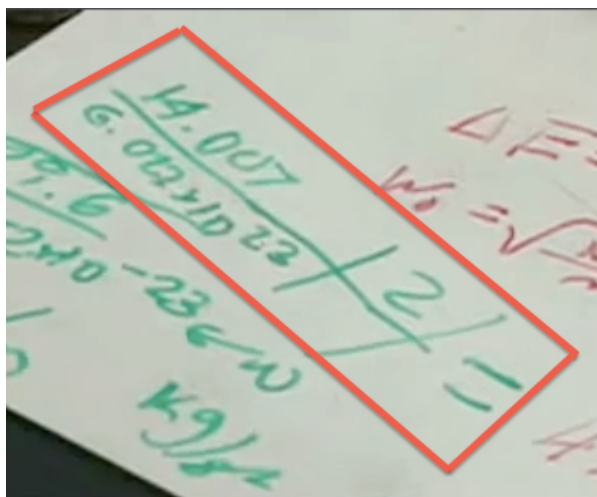


Figure 5.33: Students' whiteboard work shows S2's calculation to find the mass of a nitrogen molecule. it reads $(14.007)(2)/6.023 \times 10^{23}$. It is missing a conversion factor to change 14.007 grams into kilograms.

Figure 5.33 shows the calculation S2 has written for S3 to perform during the creation of this Issue. The calculation clearly shows that the students are converting grams/mol to grams through their use of Avogadro's number. However, S2 creates a Procedural Error without realizing it (Automatically) when he writes out the value for the mass of nitrogen with no comment towards the units being in grams instead of kilograms and no attempt at converting them (line 390). The focus here is on finding the mass of one nitrogen molecule but not necessarily on the units of that mass.

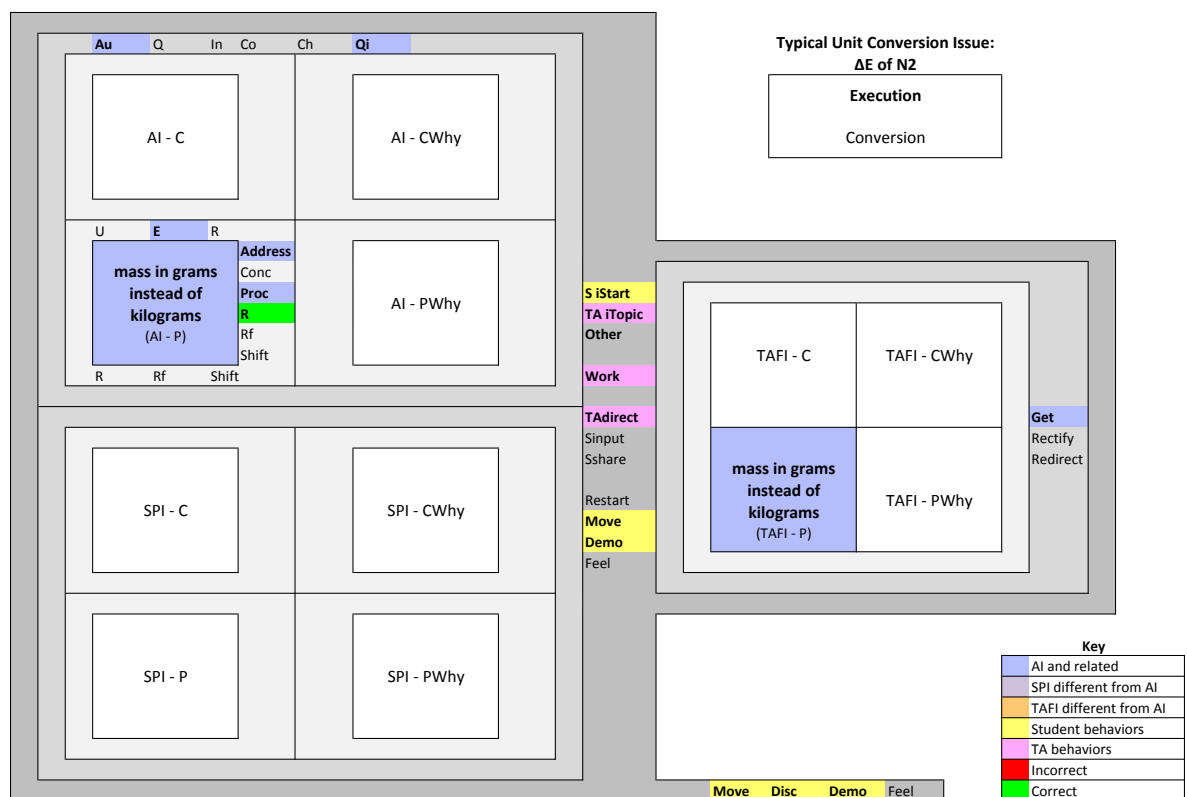


Figure 5.34: An example Issue diagram showing a typical Unit Conversion Issue from the Spectra Lab Problem 2. This diagram contains all features present in the typical story as well as features unique to the example. All features present are highlighted.

A Note on the SPI

With this kind of creation, the SPI can be absent altogether. The students have created an Issue without being aware of it, and move on until it is uncovered during an interaction. If the students do become aware of an Issue it is typically after students have calculated their final answer to a problem and submitted their answer to WebAssign. In WebAssign, they receive a red “X” indicating their answer is incorrect. Receiving the red “X” in WebAssign alerts students to the fact that there is at least one Issue they have created. However, it does not clue them in to what that Issue is.

Students may also have suspicions about their answer before submitting it to WebAssign. These suspicions are not captured in the SPI (though are represented in the framework with Other in the middle column of the diagram). I now consider that lack of identification a limitation of the framework, as it would provide more information here on where the students are just before the interaction. I reflect on this further in Section 5.7 below.

During the Interaction

At some point after the creation of the Issue, an interaction with the GTA will occur in which the Issue is brought to the forefront. Students typically begin the interaction on the topic of their final answer, not that of unit conversions (SiStart, Other). The GTA turns the focus of the group toward the topic of a unit conversion after reviewing their work and continues directing the interaction(TAiTopic, Work diagnosis, TAdirect).³⁰³¹

The Issue is Addressed with Procedural talk. Students seem to have no trouble understanding the GTA (Get), Resolving the TAFI by showing their awareness of the incorrect units. Full or Functional Resolution of the AI may not occur by the end of the interaction, but does eventually occur for all Issues in this category. Figure 5.35 highlights just these features.

³⁰Five of six TAFIs in this category also only contain a P component.

³¹In this category, the Work diagnosis only occurred in four of eight Issues. Of these Issues, there are seven unique interactions as one interaction is repeated identically. Of these seven interactions, there are only six diagnoses, as one Issue topic is brought up as an addition of extra information, rather than through the diagnose-then-discuss format that’s typically seen. This leaves four of six diagnoses that are Work. (The other two are Abbreviated.)

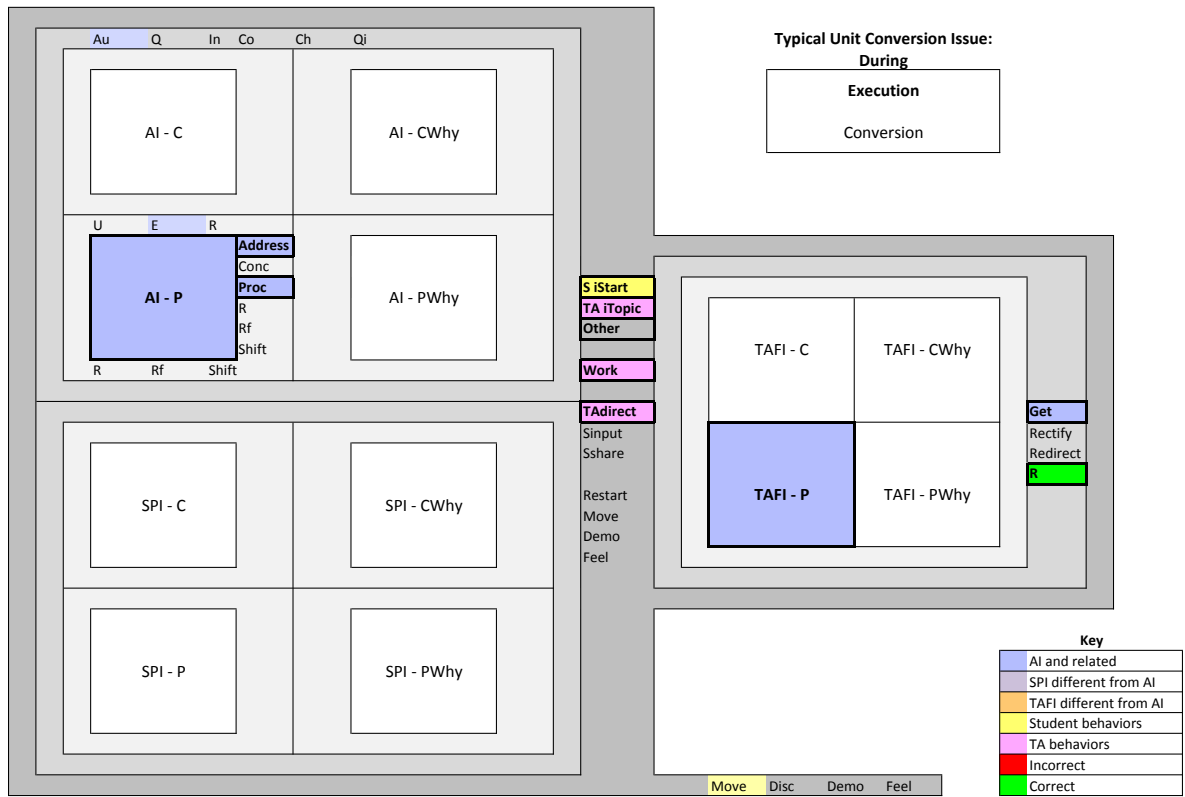


Figure 5.35: The Issue diagram for a typical Unit Conversion Issue. Highlighted, bolded features are those present during the interaction. Other common features are muted.

Continuing the example from above, this plays out in the following dialogue between the students and the GTA. At this point, the students do not think they have the correct answer, but are only focused on whether their final answer is in eVolts, an Issue catalogued separately. The GTA reviews their Work, Addressing each quantity in their solution. I focus on the Address of the mass quantity here.

397 **S1:** We can not figure this one out

398 **S3:** Ahright, we got that value (pointing to whiteboard), but that doesn't-

399 _____ (GTA cuts students off and checks their value for k_s , then continues)

400 **GTA:** and, uh, for the mass, um

401 **S2:** We got the mass of twooo (pointing to the whiteboard calculation in Figure 5.33)

402 **GTA:** Okay, by doing this, right? (pointing to the whiteboard calculation in Figure 5.33)

403 **S2:** Yeah

404 **GTA:** So this is in unit of gram (pointing to the whiteboard calculation in Figure 5.33)

405 **GTA:** ah, You find it from the perio-

406 **S3:** Needs to be kilograms

407 **GTA:** Yeah. We need to change it to kilograms.

408 **S3:** One. Two. Three. (writing in a correction)

409 **GTA:** Okay, so change this number (pointing to the whiteboard calculation in Figure 5.33)

410 _____

411 **S2:** (calculating - still within the interaction)

The students begin by identifying that something seems amiss with their answer (line 398) (Other). The GTA reviews the students' work, noticing that their mass is incorrect - a Work diagnosis that leads to the TAFI matching the AI. Evidence of this diagnosis can be found as the GTA clarifies the calculation the students are doing, focusing on the whiteboard (lines 400 and 402). The GTA then identifies the Error out loud to the students as he begins Addressing their Issue with Procedural talk (line 404). He then continues describing their number's origins (line 405). S3 cuts him off, however, immediately realizing what they have missed (Get) in line 406 and correcting it by shifting the exponent three places over showing a change in procedural moves (line 408). This is not, however the evidence of an official Resolution to the Issue because it is done by S3, not S2 (who created the Issue). Evidence for the official Resolution for S2 comes at the end and continues just after the interaction as S2 begins his own calculations to make further, correct, procedural moves. I print the post-interaction dialog in this section to briefly identify evidence of the Resolution:

412 **S2:** (calculating)

413 _____-(**Interaction Ends**)

414 **S3:** So this is a different number (erases a value from the whiteboard)

415 **S2:** (continues calculating) It's just going to change in the exponent. Four point six five one

416 nine four two times ten to the negative twenty-six (4.651942×10^{-26})

I can see by the fact that S2 begins the calculation during the interaction (line 412) and ends with the correct value just afterward (line 415) that the Issue was indeed Resolved for him during the interaction, showing a change in his ideas about what procedural moves to make. S2's calculation at the end Demonstrates the students' understanding of the correction and shows them beginning to Move forward before the interaction ends (line 411).

Post-Interaction

The students are always able to Move forward with their solution construction after the interaction indicating they can continue making moves toward executing their solution. The typical post-interaction diagram for unit conversions, shown in Figure 5.36, is very simple:

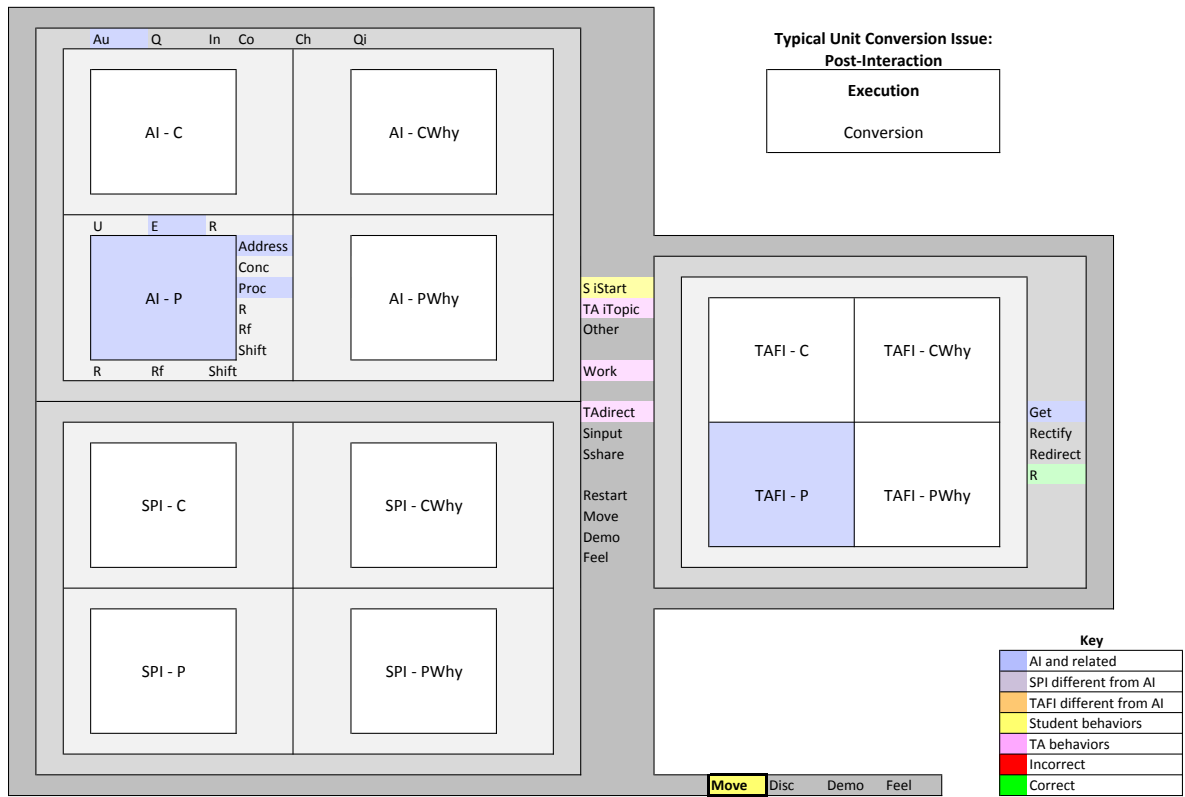


Figure 5.36: The Issue diagram for a typical Unit Conversion Issue. Highlighted, bolded features are those present after the interaction. Other common features are muted.

I briefly showed above what S2 was doing just after the interaction to determine a Resolution. Taking another look at the students after the interaction shows S2 Moving forward. Lines 414 - 415 are repeated from above, but the line numbers continue to progress.

417 **S3:** So this is a different number (erases a value from the whiteboard)

418 **S2:** (calculating) It's just going to change in the exponent. Four point six five one nine four
 419 two times ten to the negative twenty-six (4.651942×10^{-26})

420 **S3:** (writing on whiteboard)

421 **S2:** And then twenty nine point six (29.6) divided by four point six (4.6)... negative... raised
 422 to the point five (calculating)

Reviewing S2's moves after the interaction, I see that he initially finishes converting the

mass into kilograms (line 418). He then Moves on to use the new value of mass to calculate ω , evidenced by his verbalization of the calculation he's doing in line 421.

Reflections on the Typical Unit Conversion Issue

In this category, the students' process before the interaction is one of going through the motions of executing a solution and making an Error without noticing they have done so (AI - P, Error, Automatic). The students' process changes during the interaction from one of Error and lack of awareness to awareness of their Error and work to correct it (Get, TAFI - Resolution). The correcting process usually occurs, or is at least completed, after the interaction, and students continue with any more execution moves to get to the final answer (Move). The interaction is situated such that the GTA checks over students' work and identifies the conversion error in it, either telling the students or guiding them to see it (Other, Work, TAIiTopic, TAdirect). The GTA acts to bring awareness to the students of the specific quantities needing correction (TAFI - P).

The interaction focuses in on the Issue of unit conversions as well as the specific quantity needing a conversion. It is not commonly situated to guide the students to check over their own work during the interaction. If this occurred, I expect it would be represented by an Active diagnosis and/or the use of Sinput and Prompt. An example of this is shown below in Section 5.3.2 Case 1. It is also possible that the interaction directs students to check over their own work and leaves them to do that. This case would be represented by the presence of an Abbreviated diagnosis and a very generally focused TAFI - P. It would probably also include the Move, Discuss, and Demo after the interaction. However, I do not see this combination of features in the data.

Most features in the typical story here are not surprising. I expect to see students' Unit Conversion Issues created Automatically, as mistakes students make when they are not focused on those details of a problem. I expect the Issue to be Addressed with Procedural talk as well. Expounding on the concepts behind units or why one would need to convert is probably not

necessary or even helpful to the students understanding of their mistake.³² I see that the GTA reviewing students' Work leads to the TAFI - P matching the AI - P, something I also expect. In all, the typical story of unit conversions is not necessarily that interesting. What is of interest is the possibility of the interaction doing something more for the students than merely correcting their smaller procedural mistakes.

Students create a typical Unit Conversion Issue without noticing it and do not return to it before the interaction occurs. This indicates that students are not necessarily checking their work for proper units on their own. In these Issues, students may express suspicions about their final answer (either due to the answer seeming off or to an incorrect WebAssign submission), but the students don't return to review their units on their own before an interaction occurs. This is part of a larger theme in Execution Issues in which students do not check their work before an interaction with the GTA concerning the Issue occurs. The interaction, then, is an opportunity for the GTA to help students practice checking their work. I mention this theme again in following examples and reflect on it more thoroughly in Section 5.3.6. I turn next to two examples that highlight differences in this theme.

5.3.2 Unit Conversion: Two Atypical Cases

I will now review two atypical cases with Issues of unit conversions. Note that each of the following cases has more atypical features than I will discuss below, as only certain atypical features are particularly noteworthy. I will identify the focal features as I go.

Case 1: Typical Creation - Atypical Interaction

The first case is a group in which the creation of the Issue is the same as the typical Unit Conversion Issue. The atypical features arise during the interaction with the GTA. The diagram for this case is in Figure 5.37.

³²I say this since the students have already had lessons on units alone earlier in their education, and so are typically using them here instead of learning about them for the first time.

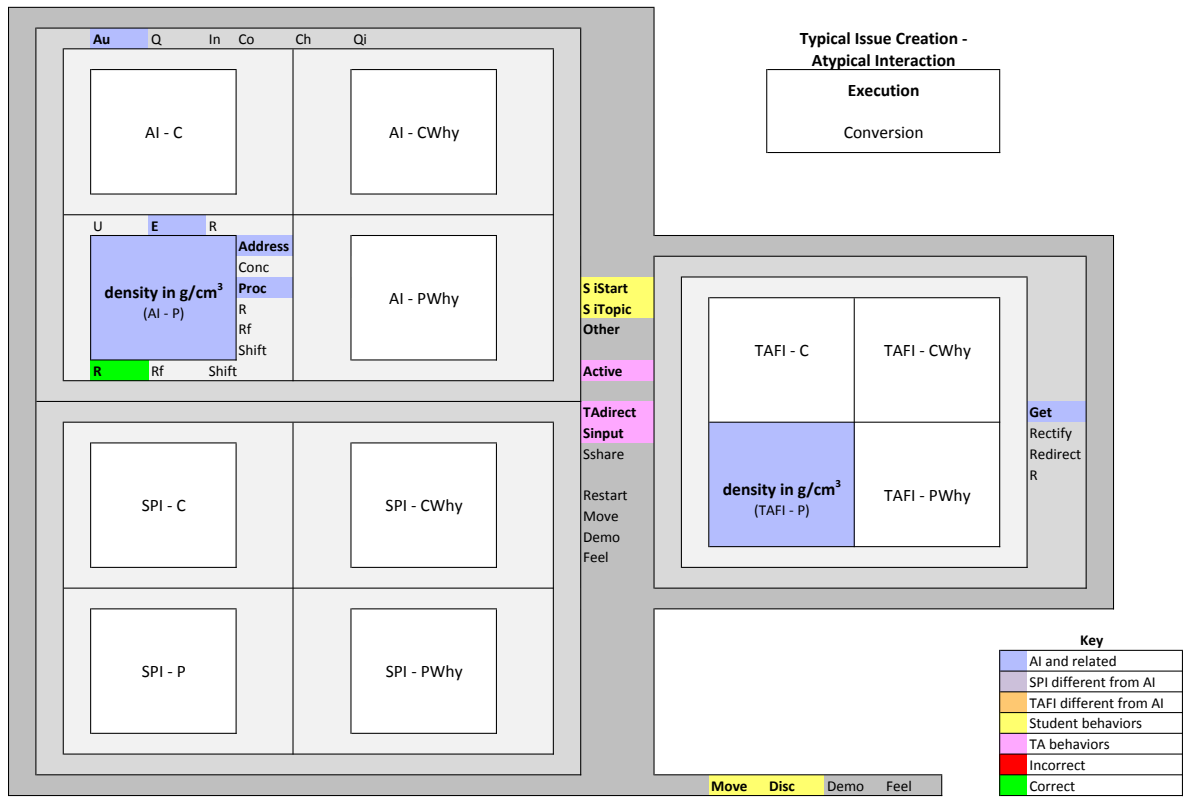


Figure 5.37: An example Issue diagram showing an atypical Unit Conversion Issue from the Young's Modulus lab - Interatomic Spring Stiffness of Brass. The creation features of this Issue are the same as the typical story (AI - P, E, Au). Some interaction features are unique to the example (Active, SiTopic, Sinput). All features present are highlighted.

In this case, students have been attempting to use the ball-spring model of atoms to find the interatomic bond length between atoms in a brass wire. They use a value for density in g/cm^3 without converting it to kg/m^3 , and they remain unaware of this Issue as they create it (AI - P - Error, Automatically). Upon completing their calculation, the students' question their final answer in an interaction with the GTA (SiStart, Other). The following, very brief interaction takes place:

- 423 **S3:** Is that the interatomic bond length? It's larger than the volume whenever you did it
 424 that way.
 425 **GTA:** that, yeah

426 **S3:** So something didn't come out right.
427 **GTA:** Yeah, something is not-
428 **S4:** Are you supposed to convert it? Like, uh...
429 **GTA:** There may be a conversion Issue. So your - your density is measured in...
430 **S2:** grams per centimeter cubed
431 **GTA:** grams per centimeter cubed
432 **S2:** So, we have to move it over... (begins correcting)

I notice a departure from the typical in some of the features through this interaction. In this case, the GTA uses an Active diagnosis, encouraging student participation through his tone of voice: casual; his body language: standing back from the group; and his verbalizations: slower and agreeing (lines 425 and 427). He seems to listen a bit more as students express their thoughts on where they might have erred in their procedure. The GTA confirms these thoughts, but does not go further during the diagnosis (ending after line 428).

In so doing, the students bring up the idea that their Issue might have to do with a unit conversion (line 428) (SiTopic). The GTA latches on to this idea, taking over direction of the conversation at this point to identify density, a specific quantity that might contain an Error in units (line 429) (TAdirect, TAFI - P). Yet, even as the GTA takes over control of the conversation, the ellipses after his mention of density indicates he is seeking student input (Sinput) as he purposefully pauses to get the students to identify the units their density is written in (line 429). In this way, he gets the students to identify their Procedural Error (line 430). I see evidence that S2 has not only answered the GTA's question, but at least begins to understand the Error as he starts to make procedural changes at the end of the interaction (line 432).

One other atypical feature here is the absence of a Resolution of the TAFI. The GTA in this case is content to bring up the quantity students need to further examine, but he does not wait to ensure students have full grasp of what is needed. He lets them work through it on their own. That the students eventually Resolve the Issue after the interaction shows they did

struggle just a bit to identify what corrections needed to be made. A quick look at the dialog after the interaction reveals this.

433 **S2:** So, we have to move it over... (begins correcting)

434 _____-(**Interaction Ends**)

435 **S1:** three decimal places

436 **S4:** It's supposed to be the negative ten.

437 **S1:** Oh, the other way.

438 **S2:** Other way?

439 **S1:** to get grams per, uh -

440 **S4:** nuh

441 **S1:** or to get to

442 **S4:** That's the right way.

443 **S3:** Yeah we're going up.

444 **S1:** We're going to meters.

445 **S4:** We're supposed to do to the negative ten, so to the right.

446 **S2:** No. You know what,

447 **S3:** That wouldn't really matter with the...

448 **S2:** you've gotta do the (mumbling and begins writing)

449 **S2:** ...grams um...a thousand grams in one kilogram and then centimeters - this will be a
450 hundred, here we go, a hundred cubed (writing out conversion)

451 **S3:** (begins calculating)

452 **S2:** over one meter cubed, so a hundred cubed times eight point nine four (8.94) divided
453 by a thousand

454 **S3:** (finishes calculating)

455 **S1:** So you move it three to the right?

456 **S2:** Yeah - I- I don't know, I've always...

457 **S2:** Want me to do it?(calculates density conversion correctly)

The students certainly know which quantity to work with and even begin the correction during the interaction (line 433). But there is no evidence that S2 has identified specifically what is incorrect or what would be correct until he talks through it (Discussion) and calculates it after the interaction (line 449). This includes some struggle as the students wrestle with how the conversion actually works before getting it Resolved.

Finally, I point out that typical features still exist in this interaction. The AI and TAFI are still matched completely and only contain the Procedural component. The Issue is still dealt with using only Procedural talk, and the students grasp what the GTA says immediately. The large difference here is the participation and contribution the students make during the interaction to identify the move they missed.

Reflection on Case 1: Typical Creation - Atypical Interaction

The interaction in this example is situated in a student process representative of the typical story. However, due to the presence of an Active diagnosis and Sinput, the interaction is situated to bring students into the process of reviewing their Work to identify possible Errors. This contrasts the typical story in which the GTA takes on the role of checking students' work overall and narrowing their possible errors to a unit conversion before identifying the quantities that need converting. While I acknowledge that the students do not do a full review of their work to find their mistake, the students contribute to the topic of where the Error might lie.

The Active diagnosis and student input in particular show a different way of approaching the students' Issue. In this case, the GTA encourages the students to participate in the process of evaluating their work, even if only a little bit, and this participation involves the students identifying procedural moves they may have missed doing. In this way, the interaction differs from the typical story and provides a picture of students participating more in checking their work.³³

³³I should note here that I do not know what would have ensued had students not brought up the idea of a Unit Conversion Issue immediately, and so I can not dismiss the possibility that the interaction might have gone completely differently had students landed on a different possible Issue.

Once the students identify the possible area of error in their work - unit conversions - the GTA specifically points to their density, identifying a particular quantity that needs correcting. This is identified in the content of the TAFI and is representative of a more typical story feature. Thus, even though students participate in checking their work, the GTA continues that step by identifying a quantity that needs correcting and focusing them directly on that quantity.

Case 2: Atypical Creation - Typical Interaction

The second atypical case is mostly atypical in the creation of the Issue. The interaction carries the typical features described earlier. But this time, before the interaction, students are more Thoughtful in their construction of the Issue. This is evidenced by the diagram in Figure 5.38 with the multi-component AI, presence of a SPI, and creation features (Q-a, Co).

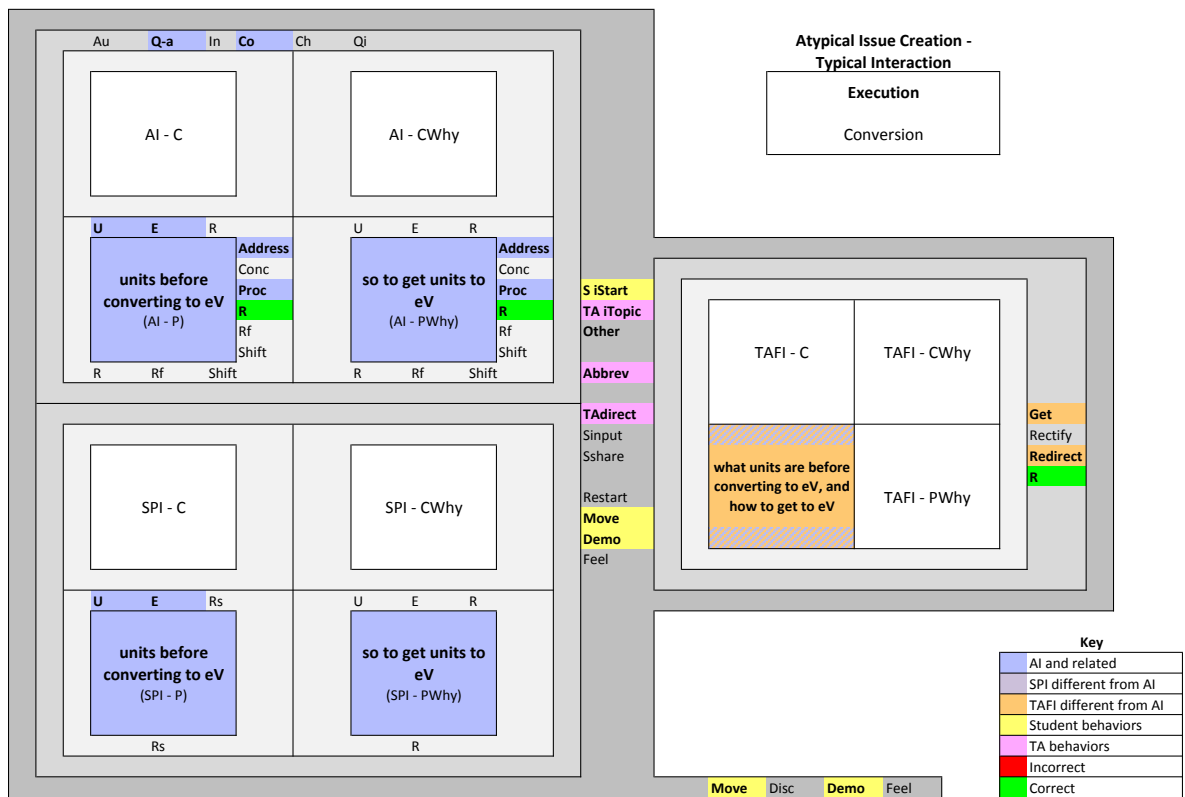


Figure 5.38: An example Issue diagram showing an atypical Unit Conversion Issue from the Spectra lab - Problem 2. Some creation features of this Issue differ from the typical story (U, AI - PWhy, SPI presence, Q-a, and Co). Interaction features are a mixture of typical and unique.

This group is working on calculating a jump between adjacent energy levels in a nitrogen molecule. The problem statement is given in Figure 5.39.

Spectra Problem 2

A diatomic molecule such as N_2 can be considered to be a quantized harmonic oscillator, with quantized vibrational energy levels which are evenly spaced.

Estimate the difference in energy between two adjacent vibrational energy levels for a nitrogen molecule. Some of the information you need to do this can be looked up in your book, but you will have to estimate at least one quantity, based on similar quantities you previously calculated. A range of estimates is accepted here:

$$\Delta E \approx \boxed{} \text{ eV}$$

Figure 5.39: Spectra Problem Statement: Problem 2

The group has calculated a final answer for the energy, but it is not in eVolts, the requested units. One group member, S2, generates the Issue by posing the following to the group:

458 **S2:** Is that value in electron volts? That seems like a really small number for electron volts.

By initially asking the question (Q_{n-a}) and following with an evaluation of their answer, S2 shows Thoughtfulness towards the idea of units and the possible need for a conversion (line 458). S1 then responds to S2, and they converse with

459 **S1:** It's whatever that is (pointing to a spot in the book)

460 **S2:** That's the units per second, so... those times seconds. We need to go from... we need
461 to ca- That's not- that's not in the right units. We gotta get that to electron volts. Um -
462 we need to get that to electron volts.

S2's description of units per second and the equation used for this problem, $\Delta E = \hbar\omega$ (line 460), lead me to infer that S1 has pointed to Planck's constant in the book when indicating what units their final answer is in: $J \cdot s$ (line 459). This sparks S2 to examine the units further and decide that they are not eVolts (line 460). I also note here that S2 does not name those units. He calls them "units," and he trails off before possibly naming them a second time with "We need to go from..." This indicates a setup for the following attempt to figure out what

those units actually are. A Collaborative effort (albeit light on Collaboration) then ensues to better understand what units the groups' answer is in.

463 **S2:** Ahright, so we multi- Ahright so we multiply this. That's K S, which is in Newtons per
464 meter. And a newton... What's-what's the, like what are the units made - all right, hang
465 on. So that's kilograms times meter per second squared (writing on whiteboard)

466 **S3:** Over meters

467 **S2:** Over meters (writing), and it's being divided by

468 **S3:** Meters will cancel

469 **S2:** So kilograms per second squared (writing on whiteboard). And then a joule (looking at
470 PC). It's, okay, so it cancels out (writing). So you got kilograms - hang on. All right. You
471 got kilograms...per second squared, and then it's gonna be kilograms times meters squared,
472 er per second squared. So the seconds are gonna cancel (writing on whiteboard). I think it's
473 gonna be meters.

S2's initial dialogue of needing to get their units into electron volts in line 460 (eV is requested in WebAssign) is the motivation for figuring out which units they currently have for the answer (AI - PWhy). The P component of their Issue then arises in trying to figure out the current units they have (lines 463 - 469). Observing S2's thought process reveals an unusual situation. The PWhy component concerns the students' next *procedural moves*, whereas the P component describes both a current procedural move *and* physics content they are trying to identify. The Thoughtful creation here highlights the effort the students, particularly S2, put in to using dimensional analysis to figure out their current units (lines 463 - 469). The SPI comes out in S2's recognition that the students have the Issue of figuring out which units their answer is in so that they can get those units to eVolts.

As mentioned before, typically, students make an Error in the Procedural component of Unit Conversion Issues, this being no exception. Since S2's final result of meters is not correct (line 469), there is an Error in the P component. However, S2 also expresses Uncertainty multiple times with:

474 **S2:** That (8.375810^{-23}) seems like an awfully small value for like electron volts.

475 ————— (and, a bit later)

476 **S2:** I don't think it's in electron volts. Know what I'm saying?

477 **S3:** yeah

478 **S2:** I'm not sure what it's in though. I'm pretty sure it's not in (undetectable). Yeah we
479 should ask the GTA if all else fails.

The Procedural component of the SPI is marked by Uncertainty as well as Error. S2's awareness of his Uncertainty is shown in his statements and in his desire to ask the GTA (line 478). Also, S2's line claiming he's "not sure what it's [units of answer] in though" comes after he claims the units might be meters. This leads me to interpret that S2 not only understands that the units the answer is in are not correct, but that he also has made an Error in his dimensional analysis.

As can be seen from the above discussion, quite a few thoughts were mapped out and Uncertainties are left hanging on this Issue of unit conversions. The interaction that follows on this Issue carries the more typical features described above. The GTA lands on the topic of the final units and directs the dialogue without seeking student input (Sinput). Enough information is exchanged that the students can quickly Resolve this Issue by the end of the interaction and change their moves to correct their units just afterward.³⁴

Reflections on Case 2: Atypical Creation - Typical Interaction

In this case, the interaction is situated to correct students' units according to the typical story. However, the students' process is unique in this category. Their process is one of checking their units. S1 attempts to interpret the units their answer is currently in (AI - P) so that they can change them to the requested units (AI - PWhy). This process contrasts the typical process in that it is very Thoughtfully laid out by S2 with contribution from S3 (Q-a, Co, AI - P -

³⁴There *are* atypical features to this interaction as can be seen in the diagram. These particular atypical features do not really change what is of interest, however - the comparison between the Thoughtfully crafted moves pre-interaction and the absence of Sinput during the interaction. I don't include dialogue here as I am simply noting the typicality of the interaction, not examining it further.

Uncertainty).

I highlight the Thoughtfulness that S2 brings to the creation of this Issue. His effort to figure out the units of the students' answer shows a push to evaluate the group's answer, even as his procedure is flawed. In this case, the GTA has an opportunity to help the students identify the units of their answer using the work they have already laid out. This might be highlighted by some combination of an Active diagnosis, Sinput, and Sshare. However, the typical interaction that follows misses the Thought behind the Issue creation and simply fixes it, allowing the students to complete the conversion after the interaction.

A typical interaction in Unit Conversion Issues is not only a missed opportunity to help students check their work, but a missed opportunity to talk with them about what and how they are checking their work when they do. I do not often see students making specific procedural moves to check their units after the suspicion about their final answer sets in. In this case, where the students have begun attempting to check their work already, the interaction with the GTA is an opportunity to capitalize on this process as it unfolds. This is in comparison to the typical case in which the students must be encouraged to *begin* checking their work rather than share what they have already done.

5.3.3 Other (5 Issues): The Typical Story

The Other category is a catchall for non-Unit Conversion Issues students create while executing their solution. These Issues include, but are not limited to students making a math mistake in their final calculation; students selecting an incorrect value for a quantity; and students incorrectly organizing their answers in a table. These Issues specifically do not concern unit conversions, but their storyline is almost identical to that of a typical Unit Conversion Issue. I will examine that story briefly. I discuss the similarity between categories further in Section 5.5.1.

Students tend to create these Issues Automatically, showing only an Error in a procedural move (AI - P). There is no Uncertainty expressed. There is also no SPI, as students typically do

not realize they have created the Issue. During the interaction, the GTA lands on the focus topic, and from there, the GTA directs the interaction. The GTA's focus matches the AI, and the AI is Addressed using Procedural talk only. The TAFI is typically Resolved, showing students understand the corrections to be made. Full or Functional Resolution of the AI may not occur during the interaction but does eventually occur for all Issues in this category. Students are able to Move forward in their solution execution after the interaction. Figure 5.40 shows the structure for a typical Issue in the Other category.

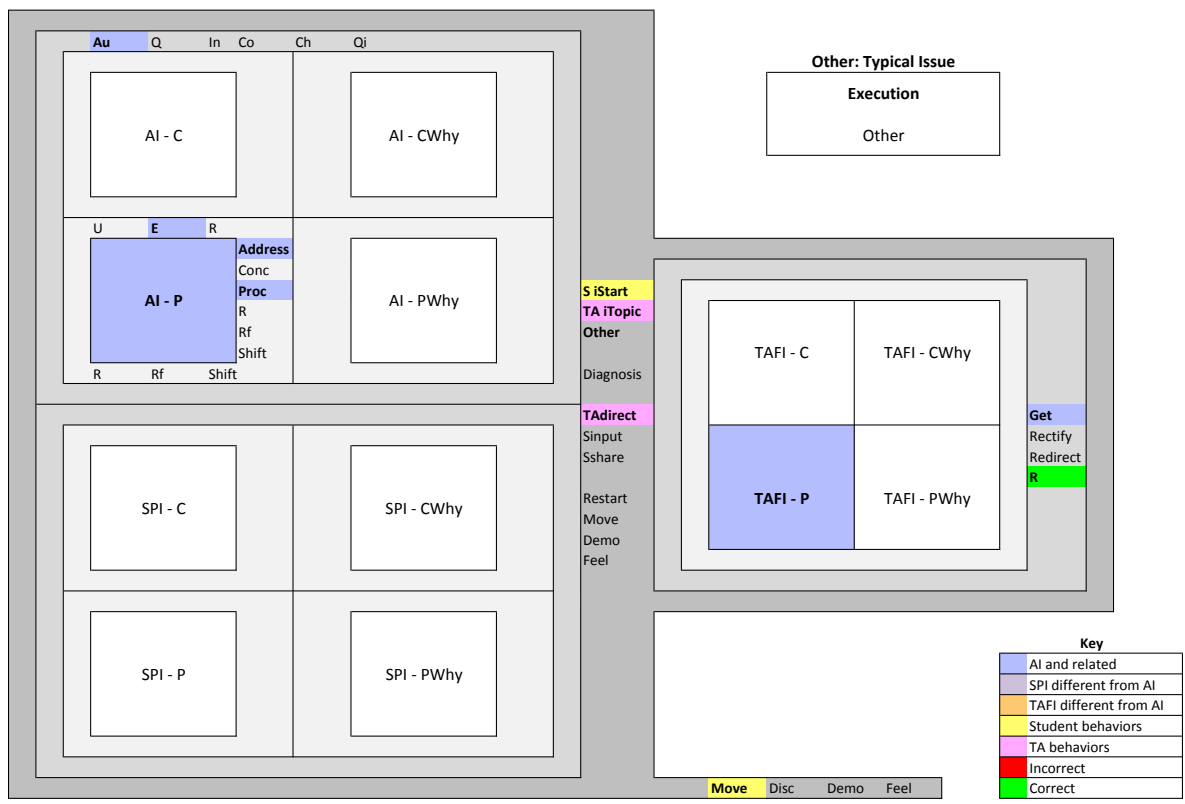


Figure 5.40: The Issue diagram for a typical Other Issue. Features that are present in at least four of five Issues are highlighted.

The only difference between this typical storyline and that of Unit Conversion Issues is a wider spread of kinds of diagnoses done by the GTA. With Issues concerning unit conver-

sions, most of the diagnoses are made by examining students' Work. In this category, only one diagnosis is made by examining Work. There is a spread across all forms of diagnosis.

Because this is the only difference between the typical story for conversions and the typical story for all other Execution Issues, it is redundant to spend time carefully scrutinizing the details of this storyline. Of greater interest is exploring a couple examples that involve different diagnoses. The following examples will highlight these diagnoses as well as present other features of interest noted in the framework.

5.3.4 Other: Example 1 - Active Diagnosis

In the first example, students are working to make corrections to their end-of-problem calculations in the Young's Modulus Lab.³⁵ They have already checked their answers with the GTA once, and an Issue was uncovered in how they calculated the cross-sectional area of their wire. They'd used the formula for circumference instead of area. This formula was corrected. In the creation of this next Issue, students are recalculating their area with the correct formula, but they make a mistake in typing one of the numbers. Figure 5.41 shows the diagram for this Issue.

³⁵These problems can be found in Appendix A, but will not be included here as they bear little weight on the current Issue.

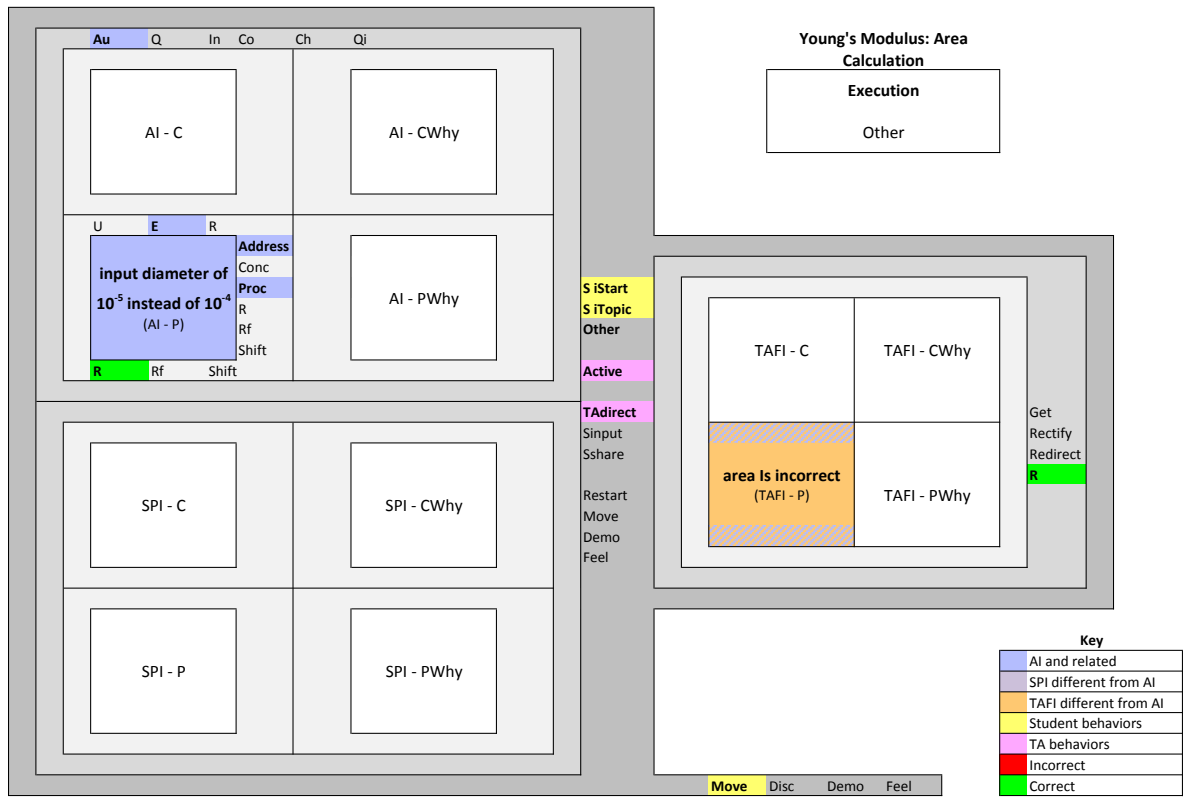


Figure 5.41: An example Issue diagram showing a typical Other Issue from the Young's Modulus Lab - Cross Sectional Area of a Wire. This diagram contains features present in the typical story as well as features unique to the example. The diagnosis is Active. The blue/orange mixed colored TAFI - P indicates that the GTA focused on a more general Issue than what the students created before the interaction. All features are highlighted.

The creation of this Issue is very typical. The students' calculation reads

$$(d/2)^2 * \pi$$

with the number $d = 0.00005m$ ($5 \times 10^{-5}m$ when the diameter should be $d = 0.0005m$ or $5 \times 10^{-4}m$). The students don't seem to notice this mistake (AI - P - Error, Automatically), and there is no relevant transcript beyond the calculation. Upon completing the calculation with the typo in it, students work to recalculate Young's Modulus and the interatomic spring stiffness, quantities that depend on this value. After doing so, they check with the GTA again.

480 **S2:** Round two.

481 **GTA:** Young's Modulus is not right.
482 **S2:** How? Young's Modulus... Let's see, it's...
483 **GTA:** K times L zero. Is that what you used?
484 **S2:** K times L zero over A. Yeah.
485 **GTA:** Let me see your calculator. (fumbles with calculator)
486 **S2:** So, slope is one over K. So K equals one over the slope. (reviewing their excel graph)
487 **GTA:** How do you use this (calculator)?
488 **S3:** It's confusing. (takes back calculator)
489 **S2:** So, just do- yeah. (reviewing PC work)
490 **GTA:** Yeah, that number K is right.
491 **S2:** That's K.
492 **GTA:** Oh. Your area is still not right. Check the calculation.

In this interaction, the GTA initially identifies that one of the students final answers is incorrect (line 481) (Other). However, the diagnosis does not end there and becomes Active after this first statement. S2, possibly confused as to how they might have made a mistake on their calculation, begins examining their work alongside the GTA. While the GTA attempts to check the calculation on the calculator (line 485), S2 reviews the students' work in their Excel graph, contributing to trying to figure out what mistake was made (lines 486, 489, and 491). In doing this, he reviews much of the work the students have done, double checking formulas and moves.

The Active diagnosis ends at line 492 when the GTA finds the mistake made in the initial calculation for area. The GTA identifies the quantity in which there is a mistake, Addresses it giving directions, and leaves. The GTA directs (TAdirect) this brief piece of the interaction but leaves the work of correcting whatever Error was made in calculating area up to the students. This can be seen in the framework by the TAFI being more general than the AI.

The diagram shows a Resolution occurring only after the interaction, indicating that the GTA's departure left students to make a few more moves beyond just picking up a calculator

and recalculating the area perfectly. I examine how this unfolds. After the interaction, S3 takes the lead.

493 **S3:** Okay, hold on. I'm on this. So (Begins calculating)

S2 also picks up a calculator and begins calculating as well. S1 checks in with S2.

494 **S1:** Are you keeping it in meters when you enter it?

495 **S2:** Yeah.

496 **S1:** Okay, wanted to make sure. Ahright.

As S1 and S2 continue, S3 grabs the mouse and does the calculation on the computer's calculator. This allows me to watch him do the calculation, and I can see he does it correctly. S2 and S3 check in when done indicating their agreement:

497 **S2:** That's what I'm getting too.

498 **S3:** That's pretty much what I'm getting.

Finally, the Issue is Resolved with the correct area found, checked by all three students (lines 497 - 498). The students then Move on to recalculate Young's Modulus and finish up.³⁶ The students come together here, checking the calculation, checking on each other's calculation, and checking in with each other to compare answers at the end.

Reflection on Other: Example 1 - Active Diagnosis

The students' process is similar to those of Unit Conversion Issues except for the different AI - P content. Students unknowingly make a mistake in a calculation (AI - P, Automatic, Error). However, their process changes during the interaction to one of checking their work for the errors (SiStart, Active diagnosis). Upon the GTA finding an Error, the students' process again changes to focus on correcting that Error after the interaction and continuing their calculations (TAFI - Resolution, AI - Resolution, Move). The interaction is situated in this process such that the GTA checks over students' Work to find an error. In this case, the students become

³⁶There is one more interaction with the GTA that confirms the correctness of their final answers, but that is included as a different segment in the No Issue category.

involved in that process, marked by the Active diagnosis, and so the interaction is situated to also allow them to participate in checking over their work. This is similar to how the interaction is situated in students' process in Unit Conversion Atypical Case 1 (Section 5.3.2).

This example identifies an Issue in which a student returns to check through the students' process and calculation during an interaction in order to find a mistake they were unaware of making before the interaction. While he does not find the particular mistake, as it is in a different calculation than he is checking, this diagnosis process shows a student checking the group's work.

Checking their work is something students did not do before the interaction, instead relying on the GTA's evaluation. But S2 seemed spurred to begin checking after the GTA's initial assessment that their Young's Modulus was not right. The GTA did not specifically ask the students to check their work. Instead, S2 took more control of this diagnosis, making it Active. I do not know why he did this, but it does seem that S2 is perplexed as to what the students could have possibly done wrong with their Young's Modulus calculation (line 482), motivating him to begin reviewing it. The Active diagnosis gives a basic picture of what students might do if motivated to review their work instead of waiting for the GTA to find their mistake as seems to be the case in several Issues. I do note that the other students did not take an active role in reviewing the group's work, and so future research might examine the possible reasons S2 participated more.

In this example, the TAFI is more general than the AI. This indicates the GTA identifies the broader region of the students' Error but not the specific Error itself. In stopping at the broader region, the GTA requires that the students work through any specifics of the Issue on their own, giving them the responsibility for further checking their work to find and Resolve their particular Issue.

The absence of Sinput here is also interesting. Typically I'd associate Sinput with additional student participation (in addition to the diagnosis). However, in this case, all participation happens in the diagnosis, and the treatment of the Issue is then very short. In fact, the treatment

is only to identify the Issue, leaving the rest up to the students. Thus, the diagnosis is the major part of this interaction, containing all of the students' - S2's - participation.

Finally the highly collaborative Resolution is worth noting. The mixture of students recalculating, checking each other's calculation, and confirming answers is representative of students working cooperatively to check their work. The strength of their cooperation is not revealed by the framework. Recognizing this limitation of the framework, I leave this observation as a point of interest and a place for possible future research. It would be interesting to better understand the factors that motivate such strong cooperation and to identify whether the interaction itself or the GTAs's behavior contributed to that. Future research may expand on the Resolution feature to better identify these characteristics.

5.3.5 Other: Example 2 - Listening Diagnosis

The second example is very atypical, and uses the Listening diagnosis. In this example, students are working through the Ball Toss Lab. The instructions for this section can be found in Figure 5.42. They are executing their solution to the ball's initial velocity using the momentum principle.

Ball Toss - Momentum Principle

Using the **Momentum Principle**, use your experimental observations to determine the initial speed.

- **Note:** Do **NOT** use numbers (except for zero) until asked to do so, and be careful of signs.
- Use m for the **mass** of the ball, v for the initial **speed**, and Δt for the **time** to reach the top. Use g to represent $+9.8$ N/kg.
- For the **system** of the **ball**, write the **Momentum Principle** for *this specific situation*
 - Initial state: just after the ball leaves your hand
 - Final state: when the ball reached its maximum height
- Solve for an expression for the initial speed, v . (**Note:** expression should have **NO** numbers!)

CHECKPOINT: Compare your results with another group.

- Now use your experimental numbers to predict the initial speed for each of your two trials.
- Show your calculations on your whiteboard.
- Check your units and the reasonableness of your values.
 - **Note:** a professional pitcher can throw a baseball at about 40 m/s (90 mi/hr).

Figure 5.42: The problem statement for finding v_i of the ball using the momentum principle in the Ball Toss Lab.

In so doing, one student selects the incorrect time value from their data table for the problem (AI - P - Error). Figure 5.43 shows the selections of their data. The diagram for this Issue can be found in Figure 5.44.

Enter your data and results here. WebAssign cannot check whether or not you have correctly recorded your data, but it can check the calculations you do based on the data you report.

In the table below, enter your data:







	Time Round Trip (sec)	Time One-Way (sec)	Maximum Height (m)
Trial 1	1.29 ✓  2.6	.645 ✓  0.645	1.49 ✓  2.04
Trial 2	1.28 ✓  2.6	.64 ✓  0.64	1.89 ✓  2.04

Figure 5.43: This is the students' data table filled in with their values. 1.29 is boxed in red to indicate the incorrect time value S1 selected for the calculation. The correct time value, .645, is boxed in green.³⁷

³⁷The WebAssign answer key is shown next to each value, and only reports an approximate appropriate answer. That is why the students' data is marked as correct even though the numbers do not match the answer key.

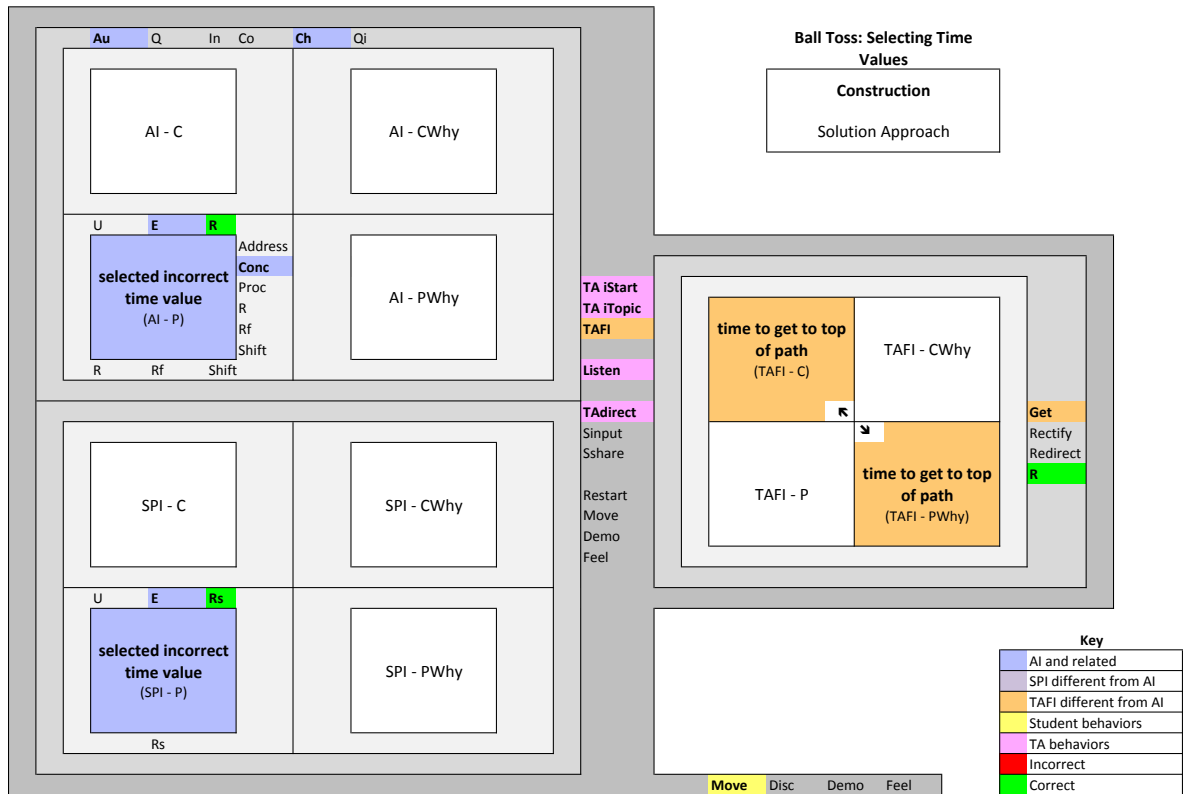


Figure 5.44: An example Issue diagram showing a typical Other Issue from the Ball Toss Lab. This diagram contains features present in the typical story as well as features unique to the example. The diagnosis is Listen. The orange TAFI -C/PWhy indicates the GTA is focused on additional physics content than what the was present before the interaction. The two diagonal arrows indicate the C and PWhy components are identical.

Watching S2 work through the calculation, S1 gives S2 the value he thinks should go in for Δt .

499 **S1:** Times one point two nine.

500 **S2:** No. It's just of half the travel, so it's point six. (writing 0.65 in place of t on the
501 whiteboard)

502 **S1:** Okay.

S1 makes the mistake of selecting an incorrect value (AI - P - Error), seemingly Automatically (line 499). S2 corrects that value (line 500), and S1 acknowledges and accepts that correction showing agreement with the correct procedural move (line 502). This combined with later evidence from S1 shows the Issue is Resolved before an interaction even begins. However, the GTA has been Listening to the entire exchange. And once this correction is complete, the GTA begins the interaction:

503 **GTA:** 'Cause that's the time to-

504 **S2:** Yeah. from the ground.

505 **GTA:** get to the highest point

506 **S1:** Okay.

507 **GTA:** where your speed's zero.

The GTA's Listening has led him to choose to add on reasoning to the corrected Issue, explaining why the correct time value is in fact correct (lines 503, 505, and 507). The explanation, echoed by S2, Addresses the Procedural component of the Issue with Conceptual talk by adding on other components that were not discussed previously by the students. In this way, the GTA helps build a more complete picture of the physical situation.

After the interaction the students Move forward, and there is evidence that S1 has, at the least, internalized the correct procedural move. (This evidence also helped me conclude the Issue was Resolved before the interaction began.) As the students do this same calculation for their next time value (two time values for the two trials, and so two separate calculations), S1 explains:

508 **S1:** It'd be the same thing divided by point six four, er, not divided by, times.

S1 selects the correct time value right off for this calculation, Demonstrating his understanding of the procedural correction. No further conceptual discussion is had. Because S1 seems to do nothing but accept the information given during the interaction, I do not know whether the interaction had any connection to the moves he made before and after it.

Reflection on Other: Example 2 - Listen Diagnosis

The students' process is selecting a value for a quantity in the problem (AI - P). An Error is made Automatically with the selection of an inappropriate value (AI - P - Error). The students' process changes to correcting the Error when a group member identifies the Error and selects the correct value (AI - P - Resolution). The process of this Issue ends here. But the interaction comes in afterward. The interaction is situated to introduce context for the correction by expanding on the reason for it, introducing a physics concept (TAFI - PWhy/C, TAIiTopic, TAdirect). The GTA is able to situate the interaction in this way by Listening to the progression of the students' process beforehand (Listen diagnosis).

The GTA does not encourage the students to examine their reasoning, which would be denoted by Sinput or an Active diagnosis. But he joins in their dialogue and contributes to their process to build a bigger picture around the procedural move.

This example is included mainly to highlight the variation in the Issues in the Other category. Beforehand, S1 makes a mistake and S2 quickly corrects it. S2 is checking the students' work as they begin executing their calculation. Thus, there is no need for the GTA to interject on behalf of the Procedural component.

In this case, the GTA Listens to the students beforehand and then adds conceptual information to S2's correction of S1's time value. Listening to the students go through their procedural Issue allowed the GTA to come in seamlessly with the other components. The addition of TAFI - C/PWhy enhances the brief discussion on procedural moves the students were having beforehand by adding in physics content reasoning. However, the GTA adds the physics content

himself instead of encouraging student participation (Sinput).

5.3.6 Reflections on Execution Issues

There are two striking features in the typical and atypical Execution Issues. The first is the Automatic creation of the Issues in combination with a lack of Active diagnoses and Sinput. The second is the fact that all Active diagnoses³⁸ occur in these Issues.

Automatic Issue Creation and the Interaction

The framework suggests an interesting theme with the identification of a particular pattern of features. The Automatic creation of Execution Issues with no SPI combined with interactions that are begun by students and begin with their uncertainty about their final answer (SiStart, Other) indicates a larger theme of students not checking their work before interacting with the GTA concerning their Issues.

Students might check their work after reaching an answer and fix multiple procedural moves without ever having an interaction with the GTA. In these cases, an interaction about those mistakes would not occur, and so instances in which that happens are not part of this dataset.³⁹ I suspect, however, that it happens less than I would like to think. The data reveals that usually students can tell (one way or another) that something is not right with their answer but they do not turn to a systematic check of various possible errors before an interaction to help them begins.

The interaction, then, poses an opportunity for GTAs to encourage students to return to their work and review their procedural moves, a valuable step in problem solving (Reif, 1994). Evidence that GTAs are taking that opportunity would show in the appearance of either or both an Active diagnosis and Sinput during the interaction as well as a more general TAFI. However, these features are not part of the typical story of Execution Issues. This indicates

³⁸There are three unique Active diagnoses in the entire dataset.

³⁹Identifying these instances would be valuable for continuing research on understanding this stage of students' problem solving process more generally.

that the students' involvement in checking through their work during the interaction is not a common occurrence. This can be seen in the example representing the typical story of Unit Conversion Issues (Section 5.3.1). The TAFI there is specific to the quantity needing converting, and the GTA reviews students' work, finding a problem with units.

Students may be able to identify immediately what the mistake is, or the correction, when first pointed out by the GTA (Section 5.3.1). But it would be beneficial to the students to learn how to systematically check their work (Reif, 1994). I speculate too, that not encouraging students to check their work, but finding their mistakes for them as the GTA more commonly does, lessens the perceived importance of the problem solving step of checking one's work. This speculation is not examined further with this research but would be interesting future work.

Active Diagnoses in Execution Issues

It is striking that all Active diagnoses occur in Execution Issues - not often, but they do occur. As I've discussed in a couple previous examples, this shows the students participating in the diagnosis in a way that has them checking or redoing a portion of their execution. In the two examples presented with Active diagnoses, students participate in the diagnosis without specific encouragement by the GTA. The diagnosis simply seems to take the form of student participation. However, that does not mean an Active diagnosis can not be encouraged by the GTA. In the final Issue featuring Active diagnosis (not discussed here), the GTA does specifically encourage student participation to diagnose the Issue by having students redo a calculation for her while she watches them. She identifies their Error when they repeat it.

It appears from the data that Active diagnoses show up when the students' Issue is not immediately obvious to the GTA through viewing whiteboard work or brief dialogue. It does not seem to crop up as a purposeful action by the GTA so much as it is either commandeered by the students or used by the GTA after a different kind of diagnosis has failed. However, the framework does not pull out these differences explicitly. More research is needed into this specific action to understand why it is present in some cases but also present so infrequently.

I think Active diagnoses may be critical to GTAs helping students develop the practice of checking over their work.

5.4 No Issue (5 Non-Issues)

In the cases of No Issue, there is no AI and no SPI, but some topic that did not appear as an Issue before the interaction is introduced during the interaction. These topics align themselves with either Execution Issues or Construction Issues. However, I did not include them in the official sorting of Issues into the content categories because the sort was based on dialogue surrounding the AI specifically. With no AI, there was not any dialogue to examine. Thus, these Issues received their own category. I'll refer to them as "Non-Issues."

However, when I review these Issues I see similarities between them and the various content categories. Non-Issues closest to Execution Issues concern checking the correctness of either an answer or the value of a quantity (Other), and construction topics concern the finding of particular quantities (Solution Approach). I list the details of the five Non-Issues below.⁴⁰

- Solution Approach
 - Non-Issue 1
 - * P - Use the mass of two nitrogen atoms (in this problem)
 - * PWhy/C - We have a diatomic molecule were each atom can move freely.
 - Non-Issue 2
 - * P - Estimate a k_s (interatomic spring stiffness) value based on the value for copper
 - * PWhy/C - At the atomic level, gases and metals have a similar k_s value.
 - Non-Issue 3

⁴⁰Because I did not validate the Issue content category they belong in, I print the specific TAFI for each Non-Issue to parse them by example.

- * P - Initial potential energy and initial kinetic energy are both zero (in the initial state).
 - * PWhy/C - There is only one particle, and it is just sitting there.
- Other
 - Non-Issue 1
 - * P - Checks value of Young’s Modulus
 - Non-Issue 2
 - * P - Checks value of ks used in equation

I’ll review these Non-Issues by the above categories.

5.4.1 The Typical Non-Issue Story: Solution Approach

The Non-Issues in this category carry the same common features as seen in the typical story of this category minus any features present before an interaction begins. As evidenced by the diagrams in Figure 5.45 and Figure 5.46, this does not leave much to discuss that I haven’t already.⁴¹ Since Solution Approach Issues are quite unique beyond their common features, it is not surprising that these Non-Issues have some unique features as well. What is interesting is that these three Non-Issues carry some of the same features that are less common in the Solution Approach category in general. Figure 5.47 shows the diagram for the common story among these three Issues.

⁴¹The TAFI being mismatched occurs by definition of the absence of an AI, and so is not interesting in this section.

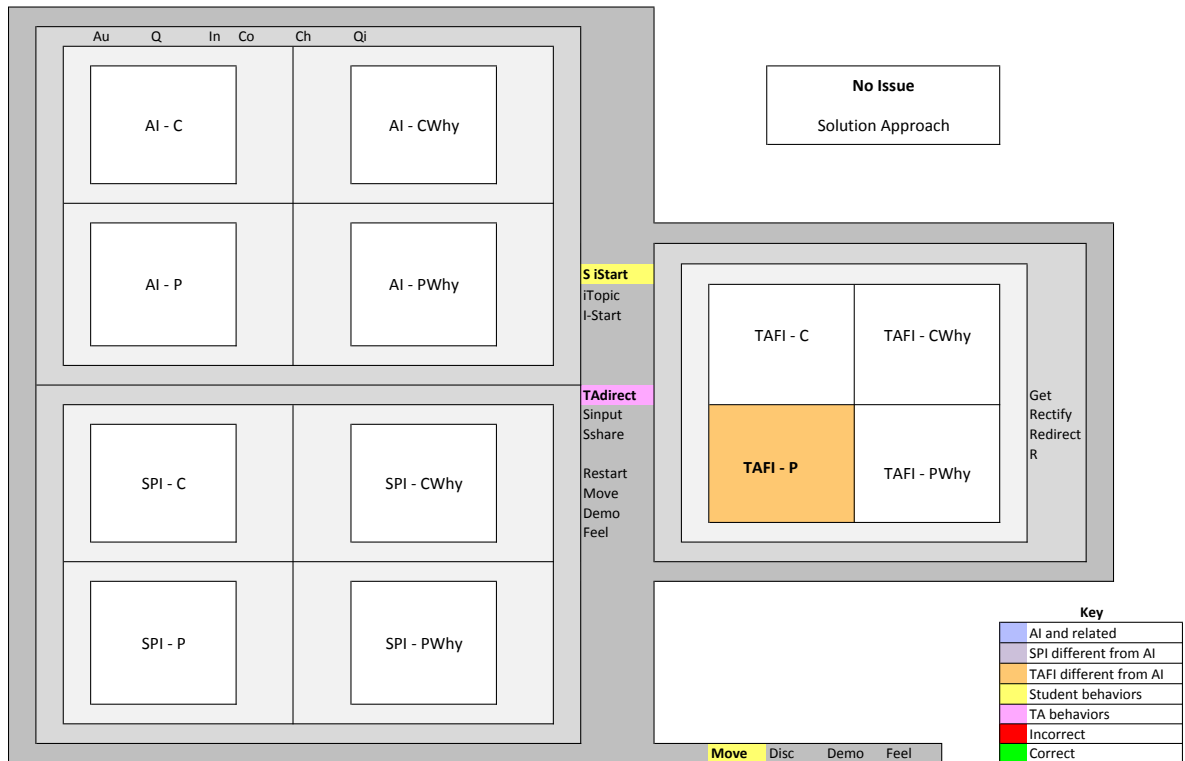


Figure 5.45: The Issue diagram for a typical Non-Issue: Solution Approach after comparing to the Construction: Solution Approach category. Features that are present in three of three Non-Issues *and* in the typical story of Solution Approach Issues are highlighted.

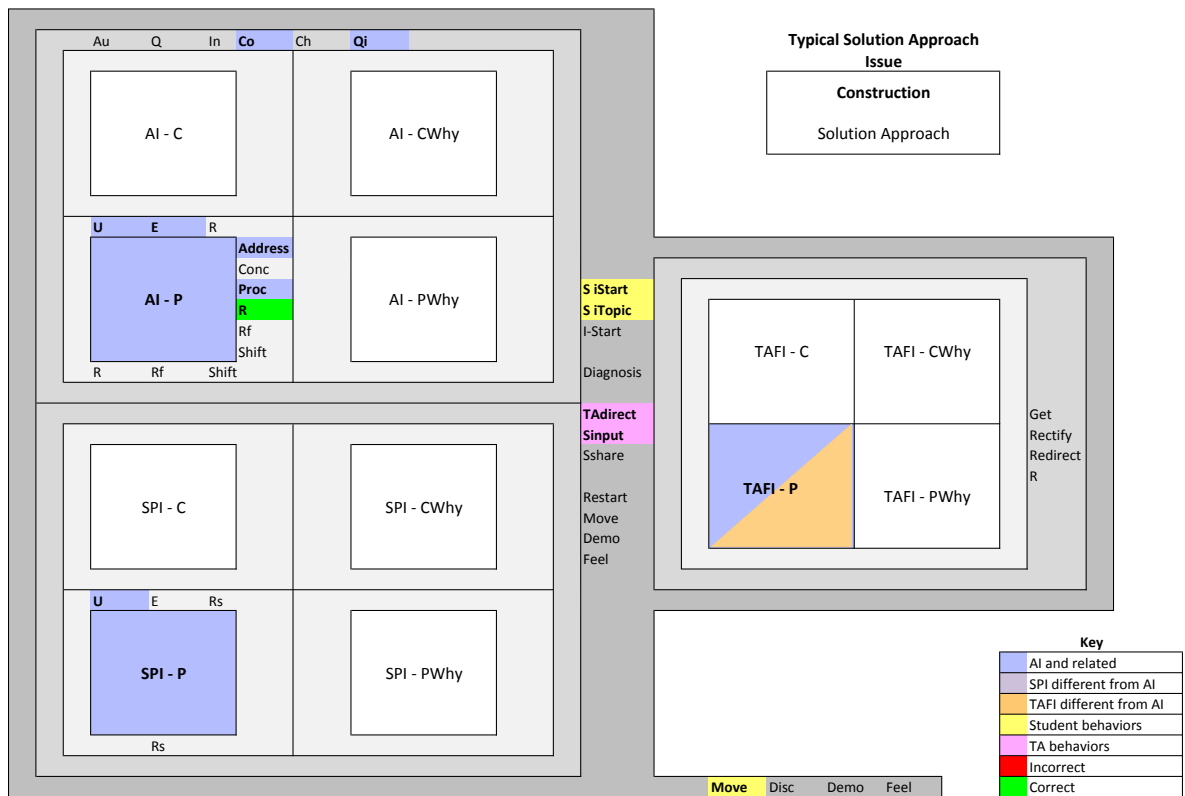


Figure 5.46: The Issue diagram for a typical Solution Approach Issue. Features that are present in at least 15 of 23 Issues are highlighted. The TAFI - P is colored both orange and blue as neither was dominant.

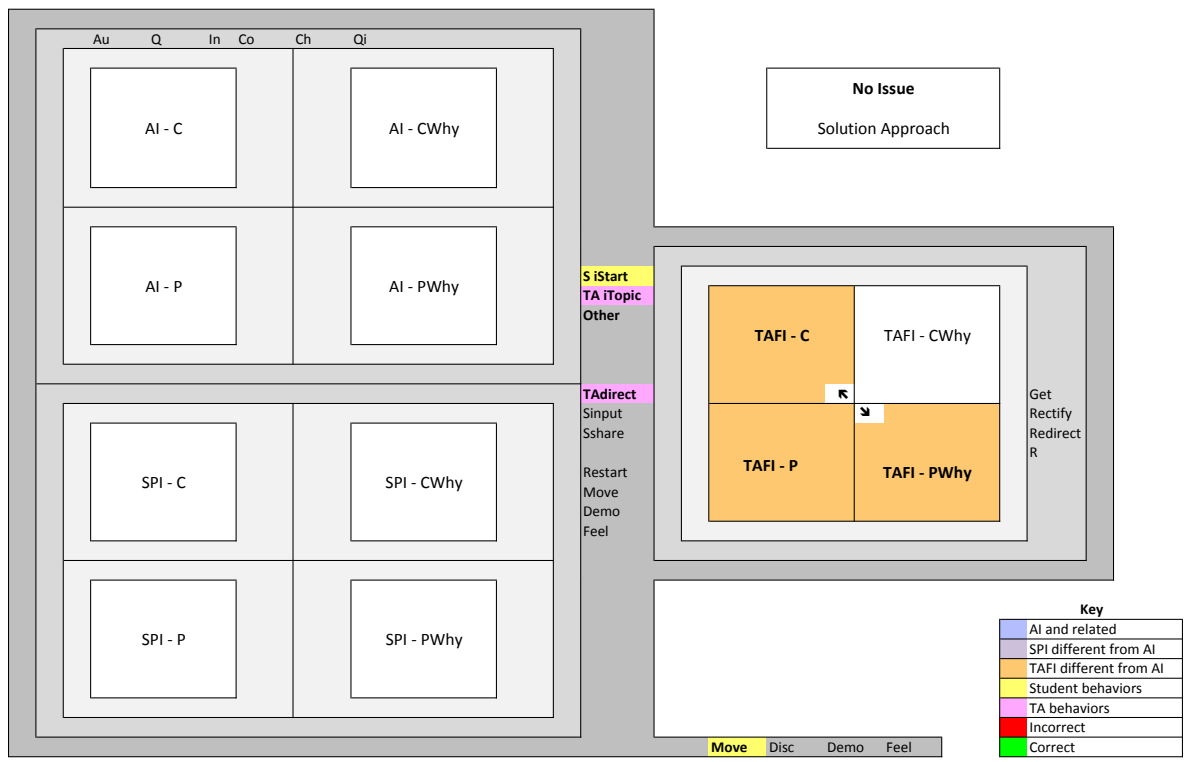


Figure 5.47: The Issue diagram for a typical Non-Issue: Solution Approach without comparing to the typical story in Construction: Solution Approach. Features that are present in all three of three Non-Issues are highlighted. The two diagonal arrows indicate the C and PWhy components are identical.

The students begin the interaction, but the GTA selects this particular topic and directs the conversation (SiStart, TAI_{Topic}, TAdirect). The TAFI includes both P and PWhy/C components, and the students are able to Move forward with their solution construction after the interaction. This story is not surprising. Since there is no Issue for the students, there would be no incentive for them to focus on a particular topic. And since the students began the interaction, it must have started with a different topic after which the GTA brought up their focus, the TAFI. I will review one example to clarify these features.

In this example, students are setting up their solution to find the ΔE of a nitrogen molecule. The full problem can be found in Figure 5.7 toward the beginning of the chapter. The students have just laid out the appropriate formula when an interaction begins, and the GTA brings up the topic of their interatomic spring stiffness (SiStart, TAI_{Topic}). I print the transcript for this part of the interaction as well as the post-interaction dialogue and will examine it together. The Issue diagram can be seen in Figure 5.48. The GTA introduces the topic with:

509 **GTA:** Uh, the tricky part is to- to estimate the value of K S. How will you do that?
510 **S2:** Well I guess we could, uh... K sub S is again..figure out, figure out the diameter how
511 far they are apart..and..
512 **GTA:** Yeah, so right now we are not giving any information about the diameter or anything.
513 So, what you can do is go to (opens book) this problem that we did while we were doing
514 Young's modulus. Uh, remember this problem?
515 **S2:** mmhmm, yeah
516 **GTA:** when you calculated the Ks of S I for..for copper? So let's say
517 **S2:** mmhmm, yeah
518 **GTA:** I give you this number Ks of S I for copper is
519 **S2:** Oh.
520 **GTA:** thirty newtons per meter
521 **S2:** Right.
522 **GTA:** Based on this number, can you estimate a good number for-

523 **S2:** Oh, okay so we know young we know young's modulus for copper so and we know it's
524 k so-

525 **GTA:** ye-uh yeah. You don't have to calculate anything. Just make a guess.

526 **S2:** Oh, okay so, we could just somewhere in the range between ten and one hundred?, uh

527 **GTA:** That's..that's actually a big range.

528 **S2:** Okay, I was trying to think (laughter) order of magnitude (gestures)

529 **GTA:** It turns out that if you take anything between twenty to fifty because the copper
530 value is thirty, it works for nitrogen as well.

531 **S2:** Okay. So how did-how'd you know to stop at fifty?

532 **GTA:** Uh..like plus minus

533 **S2:** er

534 **GTA:** twenty, yeah plus minus fifty percent

535 **S2:** Okay.

536 **GTA:** of the value but that's because that's the kind of tolerance we have on WebAssign
537 So, here you must realize we are just guessing.

538 **S2:** Right.

539 **GTA:** You're not calculating anything so the key concept to take away from this is that
540 um..whether it's a gaseous atom, or a metallic atom they have similar spring constants at
541 the atomic level.

542 **S2:** Right.

543 **GTA:** That's- that's the key point

544 **S2:** Okay.

545 **GTA:** So use that value and calculate your delta E.

546 **S2:** Ahright.

547 —————- **Interaction Ends**

548 **S2:** So for K S we're using wh-

549 **S1:** How about we just use 30?

550 **S2:** Just use 30? That-that sounds easy enough, right?

551 **S1:** So why is- what was he saying? Why- that copper would be similar to that?

552 **S2:** I think he pretty much just said all atoms are very close in there, how stiff the bonds

553 are.

554 **S1:** Okay yeah, that's what I that's what I was thinking.

555 **S2:** So, we will need the periodic table.

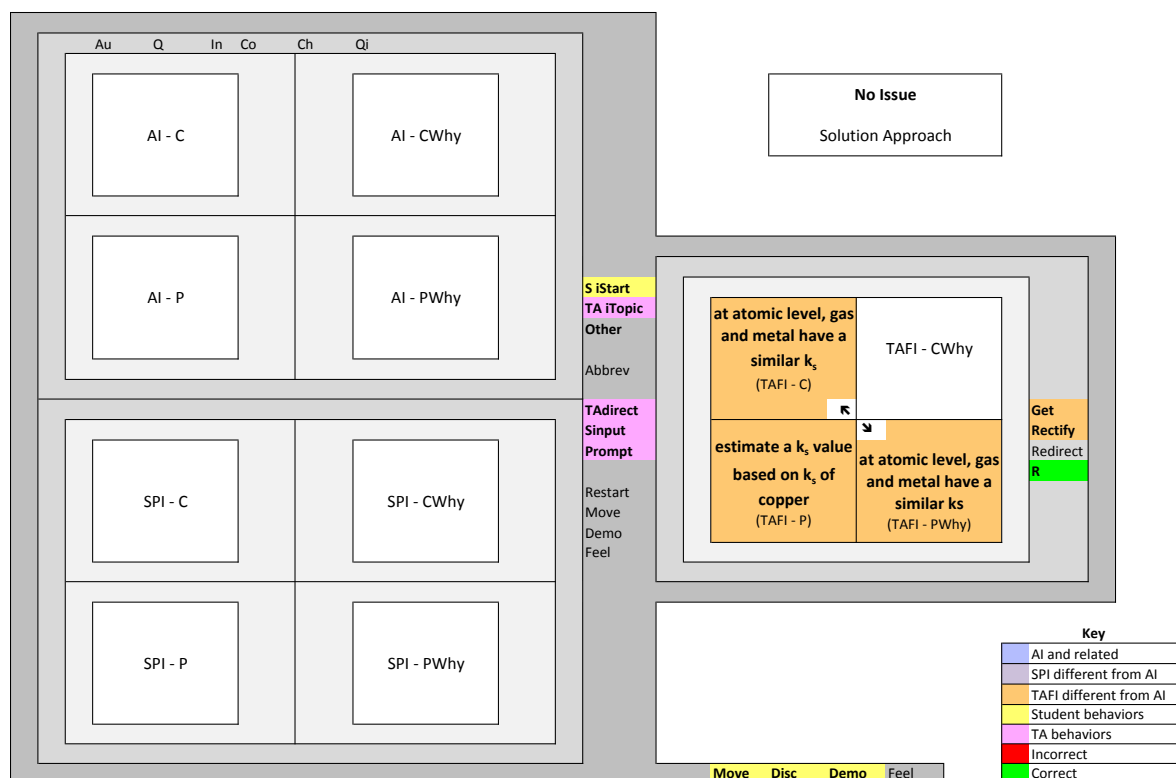


Figure 5.48: An example Issue diagram showing a typical Non-Issue: Solution Approach from the Spectra Lab Problem 2. This diagram contains all features present in the typical story as well as features unique to the example. All features present are highlighted. The two diagonal arrows indicate the C and PWhy components are identical.

The GTA initially asks the students to come up with a plan for finding k_s , selecting the

Topic (line 509).⁴² The students had not discussed how they will find the value before the GTA brings it up. S1 makes a first attempt at answering the question (line 510). As the GTA realizes S1 is not going down the correct path, he adds in more physics content information to scaffold and guide S1's strategy, continuing to direct the dialogue (lines 512 - 522). S1 tries repeatedly, getting closer to the right idea but never quite hitting it exactly. The GTA then assists him in selecting a value in an appropriate range (line 529). This is where the official procedure the GTA intended appears. S1 then asks the GTA why the value is within that particular range (line 531), prompting the GTA to explain, as well as synthesize, the main idea of the selection of the value (lines 534 - 539). I see the PWhy/C component come out of the dialogue when the GTA synthesizes the main idea behind using the particular range of values discussed (line 539). After the interaction, the students Move forward, selecting a value for k_s (lines 549 - 550) and beginning to find information for the rest of their calculation (line 555). Before this happens, S1 asks S2 for clarification from the interaction (line 551). S2 obliges, Demonstrating his understanding and continuing the Discussion (line 552).

Reflections on No Issue: Solution Approach

The students' process was one of moving through the problem without creating an Issue concerning the topic introduced by the GTA during the interaction (absence of AI components). Their process then changes during the interaction to focus on the physics content and procedural moves of the GTA's chosen topic (TAFI - PWhy/C, TAFI - P, TAIiTopic). After the interaction, students' process changes to continue constructing their solution (Move). The interaction is situated such that the GTA introduces and discusses a topic that may be a future Issue (TAiTopic, TAdirect, TAFI - PWhy/C, TAFI - P).

As shown above, this Non-Issue carries the typical features I mentioned. The GTA selects the topic and directs the interaction. He has both a Procedural focus as well as a Conceptual focus to support it. In these features, I don't find much that is exceptional when compared with

⁴²As it turns out, they only have to estimate a value, rather than calculate one.

other Solution Approach Issues.

The most unique difference between these Non-Issues and other Solution Approach Issues is the lack of creation of any Issue before the interaction. In these cases the students have not necessarily thought about the moves or physics content the GTA brings up, and then they are requested to think about them on the spot. That is to say, the students have written out their equations with the quantities or terms the GTA brings up, but they have not discussed or made any decisions about those terms before the GTA brings them up. And, given that the interaction is begun by the students on a different topic, it would seem the students do not expect to discuss these parts of the problem just yet.

The above example shows a strong student response to the TAFI with the presence of Get, Rectify, and Resolve. However, the lack of student response features in the typical story indicates that not every Non-Issue TAFI is received as well as the example above, though the students are able to Move on in their problem after the interaction. Of course, I can not say whether that is specifically due to the lack of AI, and therefore unexpected nature of this topic; lack of Prompt; or something else not identified by the framework.

5.4.2 Non-Issue: Other

The only feature *both* of these Non-Issues share with the Other category is the presence of a TAFI - P. Due to the nature of the interactions, most of the features are unique to these segments. However, there is not much worth discussing here. These Non-Issues are literally checks on values (answers or quantities) that the students either have correct or may have had a previous Issue with but have since corrected. I don't find anything interesting here to discuss beyond what I have already discussed in the Execution section above. A look at the dialogue from one of these Issues exemplifies this.

This example comes after students have made repeated mistakes in their calculation solving for interatomic spring stiffness, and they finally calculated the correct answer.

⁵⁵⁶ **S2:** (Typing in 28.96 for the value of Young's Modulus)

557 **GTA:** You got it right this time.

558 **S3:** Okay. Is that it? Twenty eight point nine six (28.96)?

559 **GTA:** Yeah

560 **S3:** Okay

561 **S2:** So that's right now-

562 **GTA:** Yeah

563 **S2:** Good. Okay.

This is, quite simply, a short interaction in which the GTA lets the students know they are correct (line 556). The students were having an earlier Issue with a particular piece of their calculation, and S3 confirms the number once more with the GTA (lines 558 - 559). In light of this example, I see no need here to reflect more deeply on this section. I reflect on all Execution Issues above in Section 5.3.6.

5.5 Review of Features Across Issue Content Categories

In this section I discuss a few specific features across all Issue content categories. In so doing, I'll review some reflections from previous sections. I identify differences and trends that are not as apparent when isolated in their individual content categories, and I discuss possible places for future research.

5.5.1 Typical Stories

In the Getting Started, Unit Conversions, and Other Issues categories, I mentioned that the common features tell not only a typical story, but also a fairly complete story. This is different from the Solution Approach category where the common features tell only a partial story with much more variation in features across the Issues.

I speculate that the presence of a fairly complete story in those three categories is at least partially due to a relative simplicity and similarity in the contents of the Actual Issues within

each of those categories. All but one of the AIs in these categories contain only one component, and all but one of those components are Procedural. Additionally, within Getting Started and Unit Conversion Issues, those components are very similar to each other. Getting Started Procedural components are representative of students expressing more general confusion: the contents of the AIs are almost the same. In Unit Conversion Issues, the contents of the AIs only differ in the specific quantity needing correction in seven of eight Issues. While the contents of Issues in the Other category are different from each other, they are all based on execution steps of a problem and seem to follow a similar story in which students make mistakes without realizing it, and the GTA helps find their mistakes during interactions. This is also often the GTAs' approach in Unit Conversion Issues, possibly lending evidence to why Issues in both those categories share very similar stories to each other as well.

In contrast, AIs in the Solution Approach category contain multiple components more often than in the other categories. This causes variation in the Issues. There are also five AIs that contain no Procedural component, causing more variation in the particular makeup of the AI. Additionally, the contents of the AIs differ dramatically from each other, representing the uniqueness of Issues students create while first constructing their solution before executing it. This also represents the difference in physics problem topics that are most clearly displayed in Issues in the Solution Approach category. Each of these Issues has a very different story following the different AIs, so there is more variation and thus a less complete typical story in this category.

5.5.2 Creation of the Issue

Most of the Issue creations are Thoughtful in Construction Issues and Automatic in Execution Issues. There are also far fewer SPIs in Execution Issues. These findings are not surprising. Finding quantities and performing calculations (Execution) is the end game in these problems. Constructing the solution that numbers will then go into is the main event. I expect students to put more thought into the construction part of the problem. I expect calculation Errors to

go unnoticed (hence the lack of SPIs).

However, as I reflected on in Section 5.3.6, Automatic creation and no SPI in Execution Issues also indicates that students are not reviewing their work before an interaction. While I certainly understand that sometimes students might just need another pair of eyes on their work, when the GTAs' eyes come in, it is before students have reviewed their own work. If students reviewed their own work, I would expect to see them interact with the GTA only in cases in which they are truly confused about their execution (as in the second Unit Conversion, Atypical example in section 5.3.2) or can't find their mistakes. In these cases, I would expect to see a Thoughtful creation feature highlighted and an SPI in the diagrams.

5.5.3 Diagnoses

Diagnoses are the connection between the physics content students express and procedural moves they make (the AI) and how much the GTA focuses on those during the interaction (the TAFI). I'll discuss Work, Abbreviated, and Active diagnoses across categories. I did not find anything compelling enough about Listen diagnoses across categories to include them here.

Work

I discussed Work diagnoses quite a bit in the Solution Approach Section 5.2.3 - Reflections on the Typical. I return to them now to draw comparisons across categories.

Work diagnoses are entirely absent from Getting Started Issues. This makes sense, as the students have no work to show before getting started on the problem. I would not expect the GTA be able to use this diagnosis by definition of the Issue content category.

Work diagnoses are present in some of the Solution Approach Issues. A Work diagnosis in this category tends to only lead to a matching TAFI half the time. This indicates that a Work diagnosis may not be adequate for identifying the appropriate AI.

Work diagnoses in Execution Issues leads to the TAFI matching the AI every time. This reveals that Work seems to be an adequate diagnosis for Execution Issues. I should note here

that all four diagnosis types lead to the TAFI and AI matching in Execution Issues. Thus, any type of diagnosis seems adequate (see page 315).

I was not surprised to see a Work diagnosis be adequate to match the TAFI and AI in Execution Issues. Nor was I surprised that they do not show up in Getting Started Issues. However, I was surprised to see that they were not adequate at matching TAFIs and AIs in Solution Approach Issues. I speculate on how this might happen.

There are multiple ideas and paths that can lead to a particular result being displayed on students' whiteboard ($W = 0$ for instance). Using only a Work diagnosis means the GTA chooses one of the possible paths that could lead to that particular result on the whiteboard. When I identify what the students discuss and do before the interaction, I identify the path they took to get that result on their whiteboard. Sometimes this path matches the GTA's, and sometimes it doesn't. This helps explain why there might be more mismatched TAFIs with the Work diagnosis and underscores the importance of using more than students' Work to diagnose an Issue in the Solution Approach category. In the Execution categories, the path students often take is very simple as it is an Automatically made Error. It can more often be readily assumed by the GTA and diagnosed by examining students' Work.

Abbreviated

The Abbreviated diagnosis seems to lead to matching TAFIs and AIs (in at least one component) in all categories. Initially this would lead me to think it is the most adequate form of diagnosis.⁴³ However, this does not seem right. The Abbreviated diagnosis, by definition, means the students don't fully explain themselves before the GTA begins to help. I would expect fewer matches in certain categories with this diagnosis alone. I break this down by category.

Getting Started Issues are based on students' confusion. In this category, an Abbreviated diagnosis is enough to verify that the students are in fact confused about what to do. This comes in conjunction with the fact that most likely they will not have anything written down on their

⁴³As in Section 5.2.3 under diagnoses, I use "adequate" to mean leading to a TAFI matching the AI in at least one component while not leaving out any components.

whiteboard either, supporting the notion that students are having trouble getting started on a problem.

While Abbreviated diagnoses are adequate at identifying student's confusion, they are not adequate at identifying what students *do* know or understand about the problem so far. They may not be able to express those things without further questions, but they may have more to express than just confusion. In the first example of the Getting Started Section 5.2.1, there were small utterances of quantities and a possible piece of information students might know. But the diagnosis ended directly after students expressed confusion. So, while Abbreviated is adequate in this category for a match, Active would be needed to further understand what the students know about a problem.

Abbreviated diagnoses seem also to be adequate at creating matching TAFIs and AIs (at least in one component) in Solution Approach Issues. However due to the increase in Issue complexity in that category, I would expect Abbreviated diagnoses to be less adequate than they are. I expect the variation in Issues in this category might be partly masking something that makes the Abbreviated diagnoses appear more adequate than they really are. It is also possible that there are clear, concise exchanges of ideas in the Issues in this category that results in the GTAs understanding where to place their focus after an Abbreviated diagnosis. If this were the case I would expect Active diagnoses to be necessary in Issues missing this clear exchange of ideas. Since I do not see any Active diagnoses, nor have I examined the clarity of the initial conversation between students and the GTA, I can not discuss this further. More research is needed on Issues in this category to further understand their variation and possible connection with Abbreviated diagnoses. Finally, as I discussed in Section 5.2.3 - Reflections on the Typical Solution Approach Issue: Diagnoses, Abbreviated diagnoses only lead to the TAFI matching the AI in more than one component once. Despite some multi-component Issues with Abbreviated diagnoses, those diagnoses do not match more than one component. This provides some evidence that Abbreviated diagnoses may not be adequate for the TAFI to *fully* match the AI. Fully matching the AI may not be necessary for helping students make certain corrections,

but it would indicate that the entire AI is revealed during the interaction, something valuable to guiding students' full process.

An Abbreviated diagnosis in Execution Issues seems to happen when the GTA does not have whiteboard work to look at and must ask the students directly about their possible Issues. When used, this is usually adequate to identify the particular Errors they have made. Again, all diagnosis types used in Execution Issues are adequate (see page 315).

Active Diagnosis

Active diagnoses are only found in Execution Issues. I was surprised by both their presence in Execution Issues and their absence in Construction Issues. I briefly dissect these by category.

Active Diagnosis: Construction Issues

There are no Active diagnoses in the Getting Started category.⁴⁴ As mentioned in the above section on Abbreviated diagnoses, an Abbreviated diagnosis seems to adequately capture students' confusion. An Active diagnosis would be required to understand more fully what students might know about the problem but can't verbalize without the proper structure. However, the GTA is able to help the students get started on the problem without probing any further for their thoughts. The presence of Move in the Getting Started typical story shows that. Thus, the data might lend one clue as to why there are not more Active diagnoses here; Abbreviated diagnoses seem adequate for Moving the students forward.

There are also no Active diagnoses in the Solution Approach category. This surprised me most since the Issues in this category are the most complex. However, I see again that Abbreviated diagnoses seem to be adequate at helping the GTAs figure out at least one component of the students' Issue. I see also that the students are able to Move forward with their solution in almost all cases regardless of the kind of diagnosis. In most cases they also Resolve at least one component. While an Active diagnosis may pull out students' ideas and give the GTA a

⁴⁴I do see an early attempt at it in one example Getting Started Issue (lines 244 - 246).

fuller understanding of the students' Issue, the data lends more evidence to the idea that an Active diagnosis is often not required to help students get to a point in which they can Move on in the problem.

In Construction Issues, I suspect that GTAs stop diagnosing an Issue when they feel they have figured out how to help the students get to the point of continuing with the problem. Rarely is an Active diagnosis needed to do this. The Active diagnosis is used to give the GTA a more complete understanding of the full Issue. It is used to pull out information the students may not have given initially. And it is used to build a common understanding with the students of what their full Issue is. These things are often not necessary to help students to the point of continuing their solution. The data reflects this last point in the lack of Active diagnoses and strong presence of Resolve and Move features. Further research is needed to examine whether GTAs stop a diagnosis when they think they can help the students get to a point of continuing their solution. That idea is only speculation as the framework does not pull this out.

Active Diagnosis: Execution Issues

I do see an Active diagnosis in the Unit Conversions category. Though brief, this takes the form of the students and the GTA working together to find the students' mistakes in their execution. As mentioned above in Section 5.3.2, the students seem to make this diagnosis Active by jumping in to offer suggestions, and the GTA follows their lead.

I see the final two Active diagnoses in the Other category. These also show the students participating in trying to find the mistakes in their solution execution. In one case, they do this of their own accord, working alongside the GTA. In the other case, the GTA has them repeat their calculation while she watches them do it.

In Execution Issues, the students seem to step in to make the diagnosis Active. The GTA still seems more prone to reviewing their Work. In the case in which the GTA purposefully has students redo a calculation, she is in fact reviewing their work as they actively do it. Thus, the diagnoses seen, while Active, are not really driven by the GTA. I would expect purposeful

Active diagnoses to perhaps put more of the responsibility for diagnosing the Error back on the students, in effect, having them review their work. I would need more research to explore why GTAs do not take this route, and instead review students' Work (with or without them) to find their mistakes.

5.5.4 AI and TAFI Mismatches

The content of the TAFI determines the physics content and procedural moves that are focused on in the interaction and whether those match the contents of the AI. The AI and TAFI can mismatch in multiple ways, as described in Section 5.2.3 - Reflections on the Typical Solution Approach Issue: TAFI Mismatches. Identifying mismatches is valuable to understanding the differences in the physics content and procedural moves focused on before and during an interaction, revealing how the interaction matches up with the students' process. When I examine how the TAFI matches the AI across the categories, a few characteristics stand out.

In the Getting Started category, the TAFI mostly matches the AI in the P component and any differences are due to the addition of information by the GTA. This includes additional information in the P component as well as the addition of other components to the TAFI that were not present in the AI. In this category, the students do not express much at all before the interaction begins, and so I would expect less matching as the GTA needs to focus on more physics content and procedures.

In the Solution Approach category, there are a range of differences in mismatched TAFIs. There are those in which the GTA adds in information. There are also those in which the the GTA leaves out components that were present in the AI. Finally, there are TAFIs that contain different content than the AI in the same components. While I might expect TAFIs to add information that is not already present in the AI, TAFIs that leave out components of the AI or are different altogether are surprising. This happens in a small number of Issues, but I do not expect it to happen at all. This indicates that the students' Issue is not always clear to the GTA, even as the GTA gives evidence that he/she thinks it is by going forward to help students

with a mismatched TAFI.

In Unit Conversion Issues the TAFIs match the AI perfectly except in two cases. In the first case, the GTA and students are both focused on a different topic that also happens to give information indirectly to their current Issue. Thus, I expect the mismatch. In the second case, the GTA adds a component to the TAFI, but only at the demand of a student in the group.⁴⁵ Thus, the two cases with mismatches are in fact exceptional.

In Other, the TAFIs and AIs match perfectly except in one case. This occurs when the GTA adds information into the interaction that was not present before the interaction and is discussed above in Section 5.3.5. The information added builds a more complete picture of the Issue in this case.

Finally, in the No Issue category every TAFI is mismatched by definition. Since there is no AI, the Issue can not have a matching TAFI.

Mismatched TAFI's occur more frequently in Construction Issues. Also, a mismatched TAFI indicates different things in different cases and categories. In Solution Approach, there is a range of possibilities with a mismatch. In all other categories, a mismatch indicates the addition of information or an exceptional case (like the focus on a different Issue that indirectly affects the current one). Further research is needed to understand the mismatches better, especially in the Solution Approach category. I have discussed these above in Solution Approach Section 5.2.3 - Reflections on the Typical Solution Approach Issue: TAFI Mismatches.

5.6 Review of Features Across GTAs

The majority of this chapter is devoted to comparing framework features across the various content categories. This is a useful comparison because it matches up with easily identifiable points in a problem solution. However, there are a few features that stand out when I compare Issues across the GTAs. A table of the breakdown of features by GTA can be found in Appendix

⁴⁵This is one of three data segments in which a student raises an idea during the interaction that necessitates another component of the TAFI. I discuss this as a limitation of the framework below in Section 5.7 but recognize it was a student addition here.

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I begin by noting that GTA 4 stood out in frequency of interactions. Data from him accounts for 42% of all data segments. Data was taken from GTAs 2 and 4 for multiple lab activities. GTA 2 accounts for 30% of all data segments. Due to the quantity of data segments for these GTAs, most comparisons were made between GTA 4 and GTA 2 and between GTA 4 and GTA 2, 5, 6, and 7 all together. GTA 4 was the only American GTA, was a member of the PER group, and had extensive teaching experience outside of his role as a GTA.

Issues are spread fairly evenly among at least three of the GTAs through all content categories except Solution Approach. Solution Approach Issues are more concentrated in GTA 2 and 4. Of the 23 Solution Approach Issues, eight are with GTA 2 and 12 are with GTA 4. While these Issues are weighted toward only two GTAs, the Issues in this category are the most unique from each other, so I suspect framework features are more dependent on some trait not accounted for (e.g. content topic within each lab).

5.6.1 AI - P Uncertainty

The feature of Uncertainty in the AI - P stands out when compared among GTAs. Comparing GTA 2 and GTA 4 shows that students of GTA 2 express Uncertainty about the AI - P component more often when creating their Issue. For GTA 2, nine of 12 AI - Ps include Uncertainty, while for GTA 4, seven out of 20 include Uncertainty.

There are many possible reasons that more Uncertainty occurred for one GTA than for another. These could include students' content knowledge, group functionality, characteristics inherent to particular students, and GTA interaction behaviors among others. Looking across the other GTAs shows that their students also expressed Uncertainty in creating Issues less than half the time, but the numbers are too small for any comparison beyond speculation. Looking across lab activities, there is a particular group of students with GTA 2 who have more frequent Uncertainty than other groups. This lends some evidence that one primary factor affecting Uncertainty is the characteristics of group members. There is less evidence tying Uncertainty to

any interaction characteristics accounted for in the framework. It is possible that the interaction affects the students' Uncertainty when creating Issues, but that the affect is not accounted for in this framework.

5.6.2 TAFI Components

The TAFI contains multiple components more often than the AI does. This indicates that the GTAs more often introduce physics content information during the interaction than students do creating the AI. Looking across GTAs, this occurs with GTA 4 more than with the other GTAs together.⁴⁶ GTA 4 focuses on multiple components in 13 of 20 Issues, GTA 2 in three of 14 Issues, and GTAs 2, 5, 6, and 7 together in six of 27 Issues. GTA 4 also brings in multiple components in more content categories than the other GTAs do. Five of the six multiple component TAFIs of the other GTAs occur in Solution Approach Issues.⁴⁷

Finally, I examined the order in which the different TAFI components are introduced in the Issues that contain multi-component TAFIs. The order is not a separate feature of the framework but can be accounted for when one analyzes an interaction to pull out the TAFI. I added a number to mark the order of the first appearance of each component. Reviewing the orders for the Issues by GTA⁴⁸ showed the beginning of a possible trend for GTA 4. Eight of 13 multi-component TAFIs were ordered from CWhy or PWhy to C or P respectively. Another two were ordered from C to P. This shows that GTA 4 more often than not focused on physics concepts and reasoning and then connected those to procedures (or conceptual ideas - C component - if no Procedural component was present at all). This is opposed to focusing on the procedure and then bringing in concepts and reasons to support the procedures (or conceptual ideas). Looking to the other GTAs reveals a variety in the order components are introduced. There are too few multi-component TAFIs (six total) to examine any possible trends with the remaining GTAs.

⁴⁶GTA 5 also shows more multi-component TAFIs, but he only has three data segments, and two of those are Non-Issues during one interaction.

⁴⁷Two of the five actually occur in the Solution Approach section of Non-Issues.

⁴⁸Since only a few multi-component TAFIs appear outside Solution Approach Issues, it was not worth comparing them across categories more than to note the rarity of them in other categories.

While I can not identify the reasons behind the GTAs' choices to include or exclude TAFI components and the order in which they are introduced to the interaction, GTA 4's patterns lead him to focus on building a bigger picture of the physical situation and then fitting that picture into the procedural move to be addressed (or conceptual idea - Conceptual component - to be focused on if the TAFI contains no Procedural component). The patterns are representative of a deeper, connected discussion of physics content, and a prioritization of reasoning and ideas that lead into procedures. The division of TAFI components in the framework diagrams provides an easy way to identify whether a GTA is focused more narrowly or broadly during an interaction.

5.6.3 Sinput and Prompt

Looking across all GTAs, GTA 4 also stands out with his frequent encouragement of student input (Sinput). GTA 4 encourages student input in 14 of 20 Issues. GTA 2 encourages input in six of 14 Issues. Combining GTA 2 and GTAs 5, 6, and 7, student input is encouraged in eight of 27 Issues. GTA 4 also encourages student input in multiple content categories while the other GTAs limit their encouragement of student input to the Solution Approach category. Further research should look into the reasons behind this lack of encouragement by most GTAs in specific categories and also why most encouragement seems to happen in the Solution Approach category.

In encouraging students' input mostly in Solution Approach, GTAs place more responsibility on the students to construct physics content and procedural moves to Resolve their Issues in this category while they do not in other categories. Thus, the responsibility for working through Issues is not placed on students equally throughout the problem solving process. However, helping students take on more responsibility for working through their Issues in all stages of problem solving may help them develop valuable problem solving skills.

GTA 4 encourages student input in all categories, so he places more responsibility on students' involvement in all parts of the problem. There are, again, many possible reasons for this that this framework does not begin to examine. I speculate that there are characteristics of

GTA 4 that motivate him to encourage student input more often and in other categories than the other GTAs.

One other feature that surprised me given the frequency of Sinput from GTA 4, was the lack of Prompt by GTA 4. My expectation was that GTA 4's level of experience and practice would come with a high frequency of encouraging students to share their ideas. In fact GTA 4 reveals a fairly low frequency of this - four of 20 Issues. GTA 4 might have more in depth discussions with students when using Prompt that are not pulled out by the framework as the framework only reveals the presence of Prompt. Thus, it is possible that even though the frequency of Prompt is low, the quality of discussions with Prompt are high. A distinction should be made in future iterations of the framework between existence of and quality of encouraging students to share their ideas. Some behaviors that might be examined to identify quality include the number of successive talking turns in which GTAs Prompt and students respond, the length of time students talk after being Prompted, whether or not their talk is cut off by the GTA, and whether the GTA repeats students' responses. Further information on quality could be gathered by comparing what GTAs are asking students to the content of the ideas students are sharing. A combination of GTA behaviors might then be ranked as more student-centered (higher quality) or less student-centered (lower quality).

Encouragement of student input is not limited to the Sinput and Prompt features. It is also revealed by the diagnosis used. Reviewing the diagnoses used for GTA 4 compared to the other GTAs, there is little difference in the use of diagnoses that are more encouraging of student input (Active and Listen). There is a difference in the use of the Work and Abbreviated diagnoses, with GTA 4 more often using Abbreviated diagnoses and GTA 2 more often using Work diagnoses. This shows that GTA 4 relies more on verbal exchanges for diagnoses than GTA 2, but these exchanges are still brief and do not necessarily probe students' ideas.

5.6.4 Student Responses

I also looked at students' patterns of behavior in creating Issues to see if there were any differences between GTAs. I wanted to see what the Issues Framework might reveal about students waiting to ask a GTA before struggling with an idea or procedure compared to trying something on their own before an interaction occurs.

It was identified in Karelina and Etkina (2007) that the students in a traditional lab more often went from sense-making to interacting with a GTA who directly answered their questions. The students in the non-traditional labs went from sense-making to trying a procedure (or writing out a possible answer depending on where they were in the lab). When they did ask questions, the GTAs tried not to answer them directly but questioned the students and helped them answer their own questions.⁴⁹ Additionally, West et al. (2013) speculated - based on anecdotal evidence from their instructors - that students who expect instructors to explain to them might tend to wait for an instructor before trying things on their own. They anticipate that this might be different for students who expect to be questioned by an instructor, or just observed by one.

In this study, I only analyzed Issues that led to interactions with the GTA. Therefore, it is possible that students often struggle, try things on their own, and are successful enough that an interaction with the GTA is not needed. This study does not examine those cases, but they would need to be examined to fully understand the scope of student independence under each GTA. This study only looked for patterns in cases in which an interaction with the GTA occurred. Thus, I will only report on differences among those cases specifically and will not generalize to students behavior outside those cases.

Unfortunately, there was a lot of explaining done by all GTAs in my study, and so I can not begin to address whether explaining itself fosters a particular behavior in the students

⁴⁹Karelina and Etkina (2007) are comparing labs and mention that the effect of the different labs was greater than the effect from any differences in GTAs. They specifically note that GTAs in the non-traditional labs were very busy and so students may have developed the pattern of sense-making leading to procedure due to not being able to get a GTA's time, rather than some other trait inherent to the GTAs' behaviors.

for these cases. However, I can compare patterns from the framework for GTA 4 and GTA 2 to see if there are any major differences. As mentioned above, GTA 4 made more use of Sinput and multi-component TAFIs than GTA 2, showing more student-centered behavior and bigger-picture focus.

To compare patterns, I first had to parse out an appropriate sample of data that could reflect what previous researchers might have observed. For instance, if students do not realize they have created an Issue (identified by the lack of SPI), then they do not have a decision to make on whether to ask a GTA for help or attempt to struggle with something longer themselves. Thus, I collected all instances of Issues with an SPI present. This discounted most Execution Issues, as most of those Issues are created Automatically without the students' awareness.

With the remaining Issues, I looked for patterns of features that indicated that students created an Issue and then had an interaction with the GTA before trying something on their own. Two patterns emerged that reflected this creation:

1. Presence of an AI - P with accompanying Uncertainty but no Error. SPI - P is also present. Students brought up the focal topic of the interaction.
2. Presence of an AI - P with accompanying Uncertainty *and* Error. SPI - P is present but different from the AI - P.⁵⁰ Students brought up the focal topic of the interaction.

A third pattern emerged in which students created an Issue and tried something on their own. This pattern involved the presence of an AI - P with accompanying Error and an SPI - P that was the same as the AI - P. In this pattern, either the students or GTA brought up the focal topic of the interaction.

Comparing the frequency of these patterns for GTAs 4 and 2 , differences are seen in how often students interact with their GTA before trying something on their own. Students have an interaction with GTA 4 before trying something on their own in six of nine cases. Students have an interaction with GTA 2 before trying something on their own in two of seven cases. Of

⁵⁰These patterns and my findings from them can only be speculative as the SPI is not validated. See Section 5.7 for further explanation.

course, as with all the results, the numbers are small and offer only examples of possibilities. That being said, this difference is interesting and should be examined further. It seems the students under GTA 4 in this study exhibit more dependence on their GTA than those under GTA 2. I speculate on possible factors that might influence this pattern.

It is possible that GTA 4 had more time to be available to students than GTA 2. GTA 4 only ever had four groups in his classroom, while GTA 2 always had eight. I took cursory notes while video-recording on the general “business” of GTA 2 and found there to be multiple times in each lab where GTA 2 was not talking with any groups.⁵¹ This would indicate that the number of groups did not have a large effect on GTA 2’s availability to the students. However, the possible availability of GTA 2 to the students is only speculative as it is not based on any validated observation protocol.

It is also possible that the groups of students observed in GTA 4’s and GTA 2’s classrooms carried inherent characteristics that influenced their decisions to interact with the GTA or not before trying things on their own. There also might be some characteristics inherent to the GTAs themselves that influence the students of GTA 4 to interact with him before trying something on their own. The framework would not pull out these differences. Other characteristics of the quality of interactions students have with each GTA may influence students’ decisions to consult with a GTA before trying something or struggling more on their own. The framework does not currently pull these out either, but it would be useful in the future to identify the possible reasons for the students’ decisions.

5.7 Limitations of the Issues Framework

I recognize that this first iteration of the framework will have several limitations, and that the framework may be strengthened with more data and further analysis. In this section I review some limitations of the framework that were found upon analyzing and reflecting on the results.

⁵¹GTA 2 consistently walked around the classroom observing groups and being physically available for interactions.

These are not exhaustive but point to areas where future analysis and research could begin improving this framework.

Students' Final Answers

One limitation is that I did not include students' suspicions about their final answer during Execution Issues unless WebAssign marked them wrong. When looking through these Issues, I found that students often seem suspicious of their final answers, sometimes before putting them into WebAssign. However, these suspicions don't always come out before an interaction. They are often brought up to the GTA at the beginning of one. These are identified in the framework only by the presence of the Other feature for how the interaction begins. However, after reviewing the results, I think there is value in finding a way to put them in the framework more specifically. This might include identifying when students bring up their final answer during an interaction as well as whether they make a statement or ask a question about its correctness. Suspicions seen before an interaction may be harder to identify or describe if not shown in the same manner. I do not currently know how the subtleties in the students' language may be parsed to identify these suspicions. However, this change to the framework would show up in the diagram as either an SPI with the content of the SPI reflecting the students' suspicion about their answer or an extension of the i-Start feature determining how the interaction begins.

The SPI

Another limitation of this framework is the lack of focus placed on the SPI. I included an SPI as a way of identifying the students' focus in relation to the AI. I used it as a divider in the Issue to separate students' perceived Issue from their Actual Issue. I did not equate its importance to that of the AI. This is evidenced by the fact that I identify the TAFI as being the same as the AI if the GTA does in fact focus on the AI at any point during the interaction. I do not consider the GTA's focus on the SPI except when it is listed as how an interaction begins.

However, reflecting on the usefulness of including students' concern about their final an-

swers in the SPI led me to see the SPI in a new perspective: the SPI is a reflection of students' thinking. It is their perception of their current process. Thus, when an interaction begins on the SPI or the GTA focuses on the SPI, the focus is on students' perceptions. This is something we tell GTAs to do in training; start from students' thinking. Yet, if the SPI is different than the AI, this focus is not captured in the TAFI. Given this new perspective and value of the SPI, future work on this project should include further validation of the SPI and adjustments to the framework to better identify its appearances during the interaction. This will lead to better understanding of students' processes and how the GTA uses students' thinking during interactions.

TAFI Mismatches

A limitation of the TAFI is that it leaves out who introduced the various components the GTA focuses on. As mentioned previously, most TAFI components that do not match the AI (orange-colored TAFI components) are introduced by the GTA. However, in three cases these components are introduced by the students for the first time during an interaction. This means they are not present in the AI or SPI as they did not appear before the interaction. The current framework does not make this distinction in the TAFI.

Also, the current framework does not account for TAFIs that match the SPI. However, as pointed out above, the SPI is a valuable area that captures students' current thinking at the time of the interaction. Thus, it would be valuable to have the TAFI account for matching that state.

Adjustments to the framework will help further detail how the AI and TAFI relate. Future iterations should better account for the various kinds of TAFIs seen so that the framework accommodates whether they are brought up by the GTA or students and how they might match the SPI as well as the AI.

Specific Modifications Needed for the TAFI

Reviewing results via the framework diagrams, I came across three diagrams that did not seem to accurately reflect the presence of all Issue components. In these cases, students brought

up ideas during the interaction that they seemed to have formed, but not expressed, before the interaction. Since the GTA focused on these ideas, they were noted as TAFI components. They were also colored orange as they did not match anything expressed before the interaction. However, the intent of the TAFI color is to identify differences between what the GTA focuses on and what the students had been focused on. Thus, since the students brought up these topics, identifying them as mismatched with the AI does not accurately represent the situation.

The framework originally did not have to account for students introducing Issue components during the interaction, as it is a rare occurrence. However, I would expect that certain conditions might support a higher frequency of students introducing Issue components during the interaction that were not brought up before. Therefore, the framework should be made to distinguish between components introduced by students and those introduced by the GTA during the interaction. These components should then be followed after the interaction as they were clearly the students' creation. In one of the three cases, there is nothing after the interaction, and the current framework accommodates the students' responses sufficiently (excepting the identification of the component as student-created). In the other case, the students carry on with that component after the interaction, and modifications should be made to account for that. Overall, future iterations of the framework should adjust for this distinction.

The framework also does not distinguish TAFI components that target a different Issue but indirectly Address the current Issue. These components do not match the AI component because they target a different Issue. For example, students create a Unit Conversion Issue with their mass term and another one with their density term. One interaction targets only the density term, ignoring a direct focus on the mass term. However, since the students must convert mass in order to convert density, the interaction also indirectly addresses the Issue with their mass term. Thus, there is a mismatch only due to a different Issue being targeted. Future iterations of the framework should distinguish situations like this from TAFIs that target the current Issue.

Diagnoses

As I reflected on the diagnoses, I mentioned the possibility that the GTAs might try different kinds of diagnoses, possibly starting with what is easiest for them and moving from there. In fact, they sometimes do use different kinds of diagnoses within the same interaction, and I had to structure the framework to create a rank for the diagnoses to select one. However, the framework does not pull out the variety or order of these diagnoses. It only identifies the one with the most focus on student involvement. Being able to identify all diagnoses a GTA tries, and in which order they are tried, would better illuminate the pattern of diagnoses used by the GTA. This would provide a better understanding of the diagnosis process and how the GTA uses students' participation to land on his/her particular focus. It also might lend more evidence to characteristics that lead to Active diagnoses. Future research should focus more on the GTA's process of diagnosing.

Sinput

I also must acknowledge here the limitations of the Sinput feature. As mentioned above in the Solution Approach category (Section 5.2.3), this feature highlights the presence of *any* encouragement of student input. This permits a wide range of encouragement from one targeted question (see line 310 in Section 5.2.3) or appropriate pause to complete use of Socratic Dialogue.⁵² I did not divide this up further because I did not see a lot of variation in the kinds of Sinput in the initial sample of data. I mostly saw targeted questions in the initial sample. The differences I did see in the range were accounted for with the Prompt feature. Looking at the entire dataset, however, there is a wider range⁵³ of dialogue that should be accounted for with the Sinput feature. Further research would adjust Sinput to account for this.

I also note that this feature does not identify the content of the specific input the students' are asked for or make. It only identifies *that* their input is encouraged. However, in some cases students are encouraged to contribute both physics concepts and procedural moves (see Sec-

⁵²Socratic Dialogue was only seen in a very brief piece of dialogue once in the dataset and once again in a coder training segment.

⁵³I still only see a wider range exemplified in a few cases. The small number of cases did not provide enough detail to expand the range of Sinput with this dataset but does illuminate the need for it to expand.

tion 5.2.2). In other cases, students are encouraged to contribute ideas for a full strategy (see Section 5.4.1). And in others, students may contribute just a formula or correction (see Section 5.2.3). Expanding on how the students' process changes through an interaction may be helped by making these distinctions systematically. Future iterations of the framework should expand this feature to connect students' input to the content of that input.

Chapter 6

Conclusions

In the first three chapters, I discussed motivation, background, and methodology for this study. In Chapter 4, I developed the Issues Framework. I showed how the framework can be used to analyze video recorded data, and I identified and discussed the patterns I found in the data. In Chapter 5, I used the framework to describe students' processes and how GTA-student interactions are situated in students' processes. The framework and its application addressed this study's research questions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

In this final chapter, I summarize the usefulness of the framework, review the results of this study, discuss the frameworks' limitations, and identify places for future research.

6.1 The Issues Framework as a Tool

The Issues Framework was developed as a tool to describe students' processes and how GTA-student interactions are situated in those processes. The framework captures several elements

of students' processes, and GTA-student interactions, identifying:

- students' development of physics content and procedural moves that lead to interactions with a GTA as they progress through solving a physics problem,
- the content and procedural moves focused on during the interaction with the GTA,
- how closely the physics content and procedural moves before the interaction match those focused on during the interaction,
- characteristics of the physics content and procedural moves as they were expressed by the students before the interaction (whether they are erroneous, expressed thoughtfully, etc.),
- particular characteristics of the GTA-student interaction that relate to how the procedural moves and physics content were addressed and whether and how students were encouraged to participate in the address, and
- how students' processes changed after the interaction in regards to the physics content and moves made before the interaction.

The Issues Framework is obviously one perspective of many that could be used to analyze GTA-student interactions and the students' processes. It is designed to be general to reveal the processes and characterize the interactions broadly, providing multiple areas for future research.

The Issues Framework also provides a visually easy way of identifying the many characteristics of students' processes and interactions with their GTA. This includes features that might be easier to identify in raw data, such as procedural errors, as well as ones that are more difficult to identify, such as collaboration in creating an error and full versus functional resolutions.

The clockwise structure of the location of features creates a visually temporal story, while the layering shows the scope of individual features. The coloring of features lets researchers know, at a glance, how to compare the features. By reviewing the colors within this structure, one can determine whether the interaction focuses on the Actual Issue students have created and which party remains dominant through the interaction. In addition, the quantity of Issue

components present, as well as features highlighted, reveals the overall complexity of the Issue. A researcher can divide up Issue diagrams by any feature of interest as well as by GTA or by Issue content category to begin to parse the various possible patterns emerging around the chosen focal point. For instance, laying out all diagrams in the Unit Conversions category side by side let me see quickly that they revealed very similar stories through their commonly highlighted features.

I found the structure of the framework and diagrams useful for quickly identifying patterns and points of interest in my data. While the features of the diagram are specific to this study's data, the overall structure of the diagram may be useful to researchers studying different phenomena qualitatively. For instance, researchers who want to examine a specific topic across well-defined temporal stages might find the clockwise encircling of said topic a useful structure to identify patterns. Using a closed shape keeps all information visually close together and allows one to build layers to examine different depths of the topic as well.

6.2 Results

I reiterate, here, the findings on agreement from Chapter 4. Table 6.1 shows again the features from which I can at least tentatively make conclusions. As mentioned in Section 4.3.2, the presence of higher simple agreement with many features and the fact that all post-discussion agreement was 100% shows that the framework does have potential to become more robust with larger sample sizes and further refining of coding instructions and definitions. I discuss this further in Section 6.3.1.

In Chapter 5, I showed the usefulness of the framework in illuminating the data by identifying the most common features of each content category and the possible typical story based on those features. The patterns reveal how the GTA-student interactions are situated in students' processes. These patterns vary somewhat based on the content category of the Issue. Here, I will review the main results of each content category.

Table 6.1: Framework features with acceptable α_K values.

Framework Features Agreement Summary

Coding Tasks	Framework Features	α_K
Issue Content Category	Getting Started vs Solution Approach	$\alpha_K: 0.89$
Characterisitcs of the Interaction	Who Directed	$\alpha_K: 0.73$
	How TA Directed	$\alpha_K: 0.77$
	Do Students Share Ideas	$\alpha_K: 0.68$
Issue Coding Survey	Inquiry Question - Qi (Survey Question 2.12)	$\alpha_K: 0.75$
	Conceptual for AI-P - Conc (Survey Question 7.3(P))	$\alpha_K: 0.82$
	Issues Beginning the Interaction - I-Start (Survey Question 12.1)	$\alpha_K: 0.73$
	Move Forward During the Interaction - Move (Survey Question 13.3)	$\alpha_K: 0.73$

Getting Started

In this category, the students' process was one of multiple students expressing confusion about how to begin the problem. This was captured in the framework by the presence of the AI - P, AI - P - Uncertainty, and Collaborate features. The GTA typically diagnosed students' confusion with an Abbreviated diagnosis and then told students how to begin the problem (TAdirect, lack of Sinput). This situates the interaction in the students' process as one of organizing information for the students so they can begin the procedure of solving the problem. The students' process changes from confusion before the interaction to understanding how to begin the procedure during the interaction (TAFI - Resolution), to beginning the procedure required by the problem after the interaction (Move).

In atypical cases, the GTA encourages the students to contribute to organizing the physics information needed to solve the problem, pulling out their ideas for how the physical situation can be represented. This is seen in the use of the Sinput and Prompt features.

Solution Approach

In this category, students' process includes creating Procedurally focused Issues as they work together to construct a solution (AI - P - U, AI - P - E, Co, Qi). The students are aware of the Procedural component of their Issue (SPI - P - U). They typically bring up the topic of their Issue during the interaction to get help changing their process. The GTA then directs the interaction and encourages students' participation in Resolving their Issue (TAdirect, Sinput). The students' process typically changes during the interaction as they Resolve the Procedural component of their Issue. After the interaction, they Move forward, continuing to construct their solution. The interaction is situated in this process often to correct a procedural mistake the students have made, including their input in the process of identifying and correcting that mistake.

Despite this typical story, the Solution Approach category had far more variation in framework features than the other categories. For instance, Solution Approach Issues contained most of the multi-component AIs and TAFIs, even though these were not part of the typical story. I speculate this variation is due, at least in part, to a wider variety of physics content and procedural moves demanded by the different physics problems. These might lead to more variation in Issue topics and distribution of the number of AI components present in this category. Issues in this category included students attempting to understand multiple different physical situations and problem statements as well as complete a variety of moves toward constructing the correct solution. Due to the variation, there was not one typical process that fully accounted for any particular data segment. And the interactions were situated in students' processes in different ways as well.

Unit Conversion

In this category, students' process is one of Automatically making a Procedural Error by not converting the units of some quantity. Often, students calculate their final answer with this Error and find that it is not quite right. They begin the interaction with the GTA with their suspicions about this incorrect final answer. This is noted in the framework with the presence of SiStart and Other in the center column. The GTA finds the unit conversion Error, drawing the students' attention to the quantity needing conversion (Work diagnosis, TAFI - P, TAdirect). The students recognize their Error and make the appropriate corrections before recalculating their answer. This is shown by the TAFI - Resolution feature, and the Move feature after the interaction is over.

In atypical cases, students either participated in diagnosing their Issue, as seen in the presence of an Active diagnosis, or created the Issue Thoughtfully, as seen with the presence of AI - PWhy, SPI, and Collaborate. The GTA may also encourage student input in determine their Error (Sinput).

Other

The students' process for this category is much the same as that of Unit Conversion Issues. This is also true of how the interaction with the GTA is situated in that process. The only differences between Unit Conversion Issues and Other Issues, as revealed by the framework, are the specific contents of the AI and the distribution of diagnoses seen. In Other Issues, there is a more even spread of the different diagnoses while Work diagnoses were typical of the Unit Conversion Issues.

In both Unit Conversion and Other Issues, students often reach a final answer but do not check their work before an interaction with the GTA begins. Interactions typically begin with students checking on or showing suspicion about their final answer (IStart - Other). From there, mistakes are identified, and the students correct them. However, they are not encouraged to check over their work or systematically check particular pieces of their calculation during the

interaction (except in one case discussed in Section 5.3.4). If they are included in checking their work (Sinput), it is often concerning very particular quantities identified by the GTA.

No Issue

Data segments in this category can align with both Other Issues and Solution Approach Issues. In this category, students have not created an Issue before the interaction (lack of any creation features). Their process is one of working through the problem with no mistakes or uncertainty toward a particular topic. However, the interaction is situated as to bring up a topic that was not an Issue beforehand and bring students' awareness to that topic (TAiTopic, TAFI). Thus, students' process during the interaction typically changes to focus on a topic they were not considering beforehand. After the interaction, students' process again Moves forward constructing or executing the solution.

Across GTAs

Examining framework diagrams across GTAs showed that GTA 4 more often used multi-component TAFIs in Construction Issues and had a higher frequency of Sinput across all categories.¹ These two features indicate that GTA 4 tended to bring a bigger picture focus to the interaction and encouraged some form of student participation in that picture. This shows a broader approach to interacting with students, one that focuses on the students' specific Issues *and* on expanding their process to include the physics context in which their Issue is situated. This is contrasted to the other GTAs whose TAFIs reveal a more narrow focus around the students' specific Issues as indicated by fewer instances of multi-component TAFIs.

Interactions Situated in Problem Solving

Overall, the interactions are situated to help move students through the physics problems they are trying to solve. They are sometimes situated to help students work through conceptual ideas

¹This is due in part to comparisons I make in Chapter 5. GTA 5 also shows these features, but he only has three data segments, and two of those are Non-Issues during one interaction.

and the organization of physics content needed to solve a problem, and GTA 4 seems to situate interactions this way more than the other GTAs. The interactions are typically not situated to help students take on the responsibility of developing specific problem solving skills.

Instead of using the problem as a context in which GTAs help students talk through their ideas and focus on particular aspects of problem solving, GTAs seem to treat solving each particular problem as the goal. This is evidenced by most GTAs' narrow focus on each students' individual Issue within a problem. This insight is drawn out clearly by the Issues Framework by the small percentage of multi-component TAFIs and scarce use of Prompt or Active diagnoses. In treating each problem as the goal, GTAs are leaving the responsibility of motivating students to express their ideas to the problem itself, and most often, GTAs are focused, with the students, on the goal of getting through the problem.

However, each individual problem is really a mechanism for student learning: for refining ideas about physics content and for developing problem solving skills to be able to work toward solving unique problems (Reif, 1994). Therefore, instead of treating each problem as the goal, as seems to be indicated by this framework, it might be beneficial to treat all problems as a medium for discussing physics ideas and developing problem solving skills. GTAs then should work, not with the *students* toward the goal of getting to the answer of each problem, but with the *problem* to collectively bring out the students' ideas and help them develop their problem solving skills. This being said, it is obviously critical to the students that they eventually reach a correct answer. But there are many paths to that answer, and GTAs can use interactions as opportunities to expand the focus of those paths.

In Chapter 1, I state that this study of students' processes and how the interaction is situated in those processes will help researchers better understand how GTAs are creating more or less interactive environments through their interactions with students. The Issues Framework reveals that, when students create Issues that are brought up in interactions with GTAs, students' processes are often focused fairly narrowly on the procedure of constructing and executing a solution. There is room to expand their processes to encompass more discussion of ideas about

physics and reasoning about their moves as well as to help them discuss these things more with each other. Interactions that create a more interactive environment would focus on expanding these processes as they help students work through physics problems. Interactions that create less interactive environments would focus more narrowly around the students' particular procedural Issue to make sure they move through the problem.

Both kinds of interactions are seen in this dataset, but those that create more interactive environments are not seen as often. When they do appear, they are more often linked to GTA 4 than the other GTAs.² However, all GTAs may benefit from further professional development focused on creating a more interactive environment.

6.2.1 Implications for GTA Professional Development

Most broadly, this research suggests that GTA training might focus more on the idea of problem solving as a mechanism for fleshing out ideas and developing skills rather than as a goal in itself. This may be done by targeting different behaviors in different Issue content categories.

For instance, the Issues Framework reveals that students who seem confused as to how to begin solving a problem (Getting Started) have not begun systematically analyzing the problem statement within their group. They seem confused as to what to do, and yet they have not begun extracting and organizing the relevant information together. GTAs typically focus on getting students to begin constructing a solution. Sometimes this includes a description of the problem or physical situation, and sometimes it does not. GTA training might focus on helping GTAs develop a short script they can practice to help students talk with each other in a more systematic way to analyze the problem and work out the first steps of constructing a solution. Or it might focus on helping GTAs figure out the best way to identify whether or not students need help organizing the initial pieces of information needed to solve the problem. These suggestions are not uncommon, and detailed implementations have already been laid out

²Again, this is due in part to comparisons I make in Chapter 5. GTA 5 also shows features that indicate a more interactive environment. But he only has three data segments, and two of those are Non-Issues during one interaction.

in previous literature on teaching problem solving (Heller et al., 2007; Polya, 1957). The results of this study reinforce the need for this kind of training.

A few features of Solution Approach Issues reveal implications for further GTA training as well. As mentioned above, students' create multi-component AIs most often in this category. However, they still do not create them often. Adding to this, TAFIs never match more than one component of the AI regardless of the diagnosis used.³ GTA training could target the effect the GTA's diagnosis has on matching or not matching students' complete Issues. It could also focus on how the GTAs might encourage students to share their ideas and reasoning with each other.

The former might be addressed by helping the GTAs be more aware of how they are diagnosing an Issue and what specifically they can learn from the different kinds of diagnoses. Understanding how one diagnoses particular Issues might make it easier to adjust that diagnosis to focus on identifying the full Issue. The latter could involve GTAs practicing asking students a few questions: Did they (the students) discuss their decisions and the reasons behind them with each other; did they agree on the result, and if not, who did not agree and why.

In Execution Issues, the Issues Framework reveals that students often have not checked their work before an interaction with the GTA begins. The GTA typically focuses on checking and identifying students' errors, often pointing out the specific quantities that need addressing. With this knowledge, GTA training on Issues in this category might focus on helping GTAs ask students more about their calculation process and the values they chose. It might also help GTAs build a practice of asking students if they have reviewed their work together and encouraging them to do so, working out with them a few things they might check on their own before interacting with the GTA again. If the patterns seen in this study are pervasive across larger datasets, GTAs could encourage students to systematically check their work with the knowledge that the students have most likely not begun to do so yet.

Most of these suggestions require that GTAs focus more on the ideas and processes presented

³Active diagnosis is not seen in the Solution Approach category.

by the students as well as their interactions with each other. Developing that practice is not necessarily easy or comfortable. It involves taking social risks and spending more time reflecting on the interactions GTAs have with their students. My suggestions are not meant as complete implementations. I make them to provide some specific focal topics, based on what is revealed by this study, that could be further developed and implemented to help GTAs deepen their teaching practice.

6.3 Future Work

In Chapter 5, I reviewed several limitations of the framework and shortcomings of the results that require future research to explore. I summarize those here.

6.3.1 State of the Issues Framework

While the framework features and structure create a complete story of students' processes and interactions with GTAs surrounding Issues, there are features that need further validation and inter-rater reliability evaluation before full acceptance of the results can occur. Currently, the framework is only partway through this process. This is due largely to the small sample of data used in this study. Coding definitions will benefit from being used on a larger sample of data and further refined.

Of course, specific features of interest can be checked for reliability individually without using the survey to fully code each new data segment. Sorting tasks, such as those described in Section 4.3, could be used on individual features to further check their reliability and refine their definitions. This would allow a researcher to further study specific features without taking the time to test reliability of all features.

I used matching tasks to validate the AI and TAFI observed in this study. However, the process of extracting those Issues from the data requires a different method of validation. I described this process and the method used to begin validating the process in Section 4.3. While this method showed some success extracting the Issues, it should be practiced and refined

on a larger sample of data to be fully validated.

Finally, the SPI has not yet been validated due to its initial role as a placeholder for students' perceived Issues. I included it to further organize the physics content and procedural moves of the students' Issue, but did not place real value on its presence. As described in Section 5.7, I now think there is value in continuing to examine the SPI. Therefore, a matching task similar to those used to validate the AI and TAFI should be used to validate the SPI. Additionally, the method of validating the extraction of the Issues from the data should include extracting the SPI as well as the AI and TAFI.

6.3.2 Framework Limitations

In Section 5.7, I described several limitations of the Issues Framework. I review those briefly now and expand on them, as they provide areas for future research.

Feature Limitations

Students' suspicions about their final answers were not included as SPIs. They are accounted for by the Other feature when they are the beginning topic of an interaction. But they are not detailed in the SPI. Further research would distinguish student behaviors that reflect suspicion about their final answer and add that into the SPI. This would permit researchers to better understand students' status before an interaction begins.

A few modifications to the TAFI would improve the process it reveals during the interaction. Identifying when a TAFI matches the SPI as well as the AI (or instead of the AI if that occurs) would reveal whether the GTA is focused on what the students perceive to be the Issue even when the students perceive a different Issue from the AI. This could be done by using the wording and coloring of the SPI in the appropriate TAFI components. Splitting components and further coloring could reveal if the TAFI contains both the AI *and* SPI.

Further modifications should include an indicator on the TAFI components that identify when a student, rather than the GTA, has introduced that component. This indicator could

be as simple as placing an “s” in the upper right corner of any TAFI components introduced by the students. Identifying these components as student contributions reveals more about the students’ roles during the interaction, as well as revealing the content of any major ideas they contribute that were not brought up before the interaction.

I mentioned, too, that the framework includes only the diagnosis with the most focus on student involvement. The diagnosis type reveals one kind of student participation (sharing an idea, showing work, etc.). But it does not reveal the full story of how the GTA uses students’ participation to come to focus on the TAFI. Revealing the full story by identifying each of the diagnosis types used and the order in which they were used (or marking them concurrently if that is the case), would allow one to better describe the role students take in contributing to the TAFI. Future research might add all four possible diagnoses to the framework diagram, highlight the ones used, and mark their order with numbers in the appropriate cells.

Sinput and Prompt are other features that should be modified to provide a better description of how the GTA encourages student participation during the interaction. Sinput only reveals whether the GTA encourages student participation in any way but not how it is done. The Prompt feature further distinguishes the kind of participation encouraged as it identifies when a GTA requests students’ ideas. However, there can be quite a range of participation sought by the GTA. The framework should be modified to account for this variety as well as for the actual student input given by the students. This would reveal more about the students’ process and the relationship between the GTA and students that affect changes in the students’ process. Sinput and Prompt modifications could include the use of a range of student input categories similar to those detailed by West et al. (2013) and adjusted based on the data.

Non-Feature Limitations

As discussed in Section 3.2.6, GTAs recorded in the Spring 2012 semester were representative of the GTA population for that semester. However, data from only one of those GTAs was used

in this study.⁴ I do not know if the other GTAs used in this study were representative of their populations. I know that GTA 4 was the only domestic GTA, had extensive teaching experience, and was a member of the Physics Education Research group. It is possible that the bias of GTA backgrounds had an affect on the emergent framework features. Further research should test the Issues Framework on a larger population of GTAs with a more even distribution of background variations. However, since GTA 4's background was very different from the other GTAs, and since half the data came from GTA 4's interactions, a wide range of GTA characteristics are represented in this data and accounted for in the framework. Thus, I expect that the framework would satisfy a larger, varied population.

Additionally, this framework emerged from data of only five GTAs and seven different student groups. As future research gathers larger sample sizes of data to refine the framework, data should also be gathered on larger populations of GTAs and students to further refine and validate the framework.

I expect this framework will be useful for analyzing how GTA-student interactions are situated in students' processes during problem solving in a variety of curricula due to the overall generality of its structure and features. However, the framework was developed using data from only a few physics problems presented in one innovative curriculum. It was developed using different kinds of physics problems, differing in topics and presentation. But it has not yet been tested on different curricula or a large variety of problems. Future research should attempt to further validate the framework by applying it to data from a variety of curricula and problem (in addition to a larger population of GTAs and students).

Specific to this is the difficulty I had attempting to use the framework on Issues created during multiple choice and multiple select problems in WebAssign. I discussed this extensively at the end of Section 4.1.9. Future research should test the framework's possible usefulness on paper- based multiple choice and multiple select problems.

⁴The other two GTAs recorded that semester had no interactions with their students during the problem solving activities selected for this study.

6.3.3 Future Research Suggested by the Framework

Most future research centers around reliability, validation, and refinement of the framework itself. Certainly, reliability and validation should continue before considering further research based on the results of the framework. However, the results presented in Chapter 5 do suggest areas of interest for that research.

In Section 5.2.3, I discussed the beginnings of a pattern of diagnoses that did not lead to the TAFI adequately matching the AI in Solution Approach Issues. The Work diagnosis seemed to be the least adequate at creating this match. The Listen diagnosis was mixed, and the Abbreviated diagnosis was the most adequate. It would be interesting to continue fleshing out this pattern, if it truly exists, and to continue understanding the role of each kind of diagnosis. A future study may experimentally test the adequacy of each kind of diagnosis individually, further bringing to light the benefits and limitations of the various diagnoses.

In that section, I also mentioned the beginnings of a possible pattern in how a full Resolution of an Issue might be related to how well the TAFI and AI match. The Issues without full Resolutions in the Solution Approach category only occur for multi-component AIs alongside TAFIs in which more than one component is different from the AI (six Issues). Further research would continue examining a larger sample of data on Solution Approach Issues to see if this pattern becomes pervasive or disappears.

In some interactions addressing Execution Issues, certain students actively participated in the diagnosis of their Issue. The reasons behind this voluntary participation are not a focus of this study but would be interesting for future research. Studying the characteristics of voluntary participation in an Issue diagnosis might help reveal the kinds of characteristics a GTA could encourage from other, less active group members.

Students almost always Move forward after an interaction with the GTA, regardless of whether or not there is a full resolution. Thus, this study captures a change in their process from creating the Issue and not being able to move forward, to either Resolving or at least abating the Issue and Moving forward. This study does not reveal how students' Move forward:

it does not describe whether they are more procedurally or conceptually focused after the interaction or whether their moves are more automatic or thoughtful afterward. Describing these details would provide more information on the students' process and allow researchers to better identify the various effects an interaction has on the students' processes.

I mentioned briefly, in Section 5.3.6, that when the GTA focuses on finding students' mistakes in Execution Issues instead of placing that responsibility on the students, he/she might lessen the importance of the problem solving step of checking one's work. I speculate that there is a connection between how GTAs encourage students to focus on the various steps of problem solving and how students focus on those steps. For instance, I expect that GTAs who repeatedly encourage students to check their work for errors will have students more often check their work when the GTA is not around. In this study, I saw GTAs mostly focus on finding students' errors, and in those cases, students were not checking their work beforehand. To further understand how students' might respond to interactions during this step of problem solving, future research would have to examine both what students do in the absence of GTA-student interactions as well as identify interactions that specifically guide students to check their own work. The Issues Framework can be used in its current form for the latter, but would have to be modified for the former. Modifications would include removing all features specific to the GTA-student interaction and adding features that describe in more detail how the students address their own Issue. The clockwise temporal structure, layering, and coloring would still be useful in creating a visual description of these Issues.

The Issues Framework reveals that students do not often communicate the reasoning behind their moves when they create Issues that lead to interactions with the GTA. Thus, in Issues that involve interactions with the GTA, the GTA may play a critical role in helping students express their ideas and reasoning. Future research should examine the reasons behind why GTAs do not frequently encourage students' to share their ideas more with the goal of designing professional development to target this practice.

Finally, it is possible that students do discuss and reason through their moves and even re-

solve their own Issues without interactions with the GTA. When AIs the students have created *do* result in interactions with the GTA, most AIs focus on Procedural components only. Discussing their reasoning is not a typical occurrence for the students. Further examining students' processes with and without interactions with the GTA will continue to build a description of students' processes and identify differences between processes that lead to interactions with the GTA and those that do not. Thus, future research should look into the Issues students create and how they are addressed when they do *not* result in an interaction with the GTA.

6.4 Final Remarks

I developed the Issues Framework to describe how GTA-student interactions were situated in students' processes. The Issues Framework was guided by my research questions:

1. How do the GTA's interactions with students relate to the physics content students express before, during, and after those interactions in an interactive environment?
2. How do the GTA's interactions with students relate to the procedural moves students make before, during, and after those interactions in an interactive environment?

The GTA-student interactions related to the physics content students expressed and procedural moves they made through the addressing of Issues students created while constructing solutions to physics problems. The Issues Framework emerged to more fully describe this relationship.

Four different categories of Issues⁵ emerged spanning the problem solving process. Using the framework, I found that students' procedural moves and physics content expressed differed in each category, respective to where they were in the problem solving process. Despite these differences, students often focused narrowly on procedural moves with the physics content expressed through these moves. Sometimes, but not often, students focused more directly on physics concepts and how they supported the procedural moves. Interactions with the GTA

⁵Four categories includes integrating the Non-Issues into the Solution Approach and Other categories.

affected a change in students' moves and expressions, typically leading to them resolving their Issue in some way either during or after the interaction. These interactions were also generally focused narrowly around procedural moves, aligning with the students' narrow focus. Slightly more often than students, GTAs expanded the focus of an Issue during the interaction to include physics concepts and reasoning supporting procedural moves. After the interaction, students procedural moves and expressions of physics content eventually changed to focus on topics different than the original topic of their Issue, showing the interaction helped them move past their Issue.

The Issues Framework is a useful tool for generally describing students' processes surrounding interactions and how their interactions with GTAs are situated in those processes. Future research will hopefully refine and expand on this framework, making it even more useful and more broadly applicable to a wider variety of data.

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APPENDICES

Appendix A

Problem Solving Activities

A.1 Young's Modulus

A.1.1 Purpose

In this lab you will:

- investigate the spring-like properties of a straight wire,
- discover the “stretchiness” of a material, independent of the size and shape of an object,
- relate macroscopic “stretchiness” of a material to microscopic stiffness of the inter-atomic bonds.

Some useful equations and constants are given at the end of this document.

A.1.2 Questions to Explore

1. Is a solid metal straight wire like a spring? If so, in what ways? If you consider the wire to be a spring, how does spring stiffness compare to the coiled springs used in the previous lab?

2. How can one express the spring-like properties of the particular metal in a way that is independent of the size, shape, and physical dimensions of the wire (Young's modulus)?
3. How can one relate the macroscopic spring-like properties of the particular metal to the stiffness of that metal's interatomic bonds (interatomic spring stiffness).

A.1.3 Background

Spring forces

The magnitude of the force exerted by a spring on an object attached to it is linearly proportional to the absolute value of the stretch of the spring. The spring constant k_s , represents the stiffness of a particular spring, and has units of N/m. The stretch can be positive or negative, and is defined as the difference between the current length of the spring L and its original, relaxed length L_0 . Sometimes the symbol ΔL is used to represent the stretch: $\Delta L = L - L_0$.

Since we will be dealing with both a macroscopic and a microscopic stretch in this lab, we will refer to the **macroscopic** stretch as ΔL . This makes the force law for a spring:

$$|\vec{F}| = k_s |\Delta L|$$

Young's modulus

The stiffness of a wire depends on the length of the wire and the thickness of the wire, so different wires made from the same metal will have different stiffnesses. It is useful to have a measure of the stiffness of a particular material (such as aluminum, copper, gold, carbon nanotubes), independent of the dimensions of the wire.

Calculating Young's modulus is a way to measure the "springiness" of a material and factor out the size and shape of the particular wire. Young's modulus is the ratio of:

Force exerted per square meter of cross-sectional area (F/A) ("stress")

to

Fractional stretch of the wire ($\Delta L/L_0$) (“strain”)

$$Y = \frac{(F/A)}{(\Delta L/L_0)}$$

Interatomic spring stiffness

Our simple model of a solid object is a bunch of tiny balls (atoms) that are held together by springs (chemical bonds). The relaxed length of the little spring between two atoms (the interatomic bond) is just the distance from the center of one atom to the center of the other atom, d , which for our model, is just twice the radius of the one of the atoms since the electron cloud of the atom fills in the extra space. A simple cubic arrangement of the atoms would mean that the volume that each atom fills would be $d \times d \times d$ and would have a cross-sectional area of $d \times d$.

Since the interatomic bonds are modeled as springs, they also have a stiffness $k_{s,i}$ that relates the interatomic force to how much those interatomic bonds stretch. We will use s to refer to the **microscopic** stretch.

$$|F| = k_{s,i}|s|$$

A.1.4 Experimental Setup

Equipment: a straight metal wire stretched on a frame, with a hanger for weights and a millimeter scale for determining the position of the end of the wire, Vernier caliper (see the Measuring with Vernier Calipers Section for how to read).

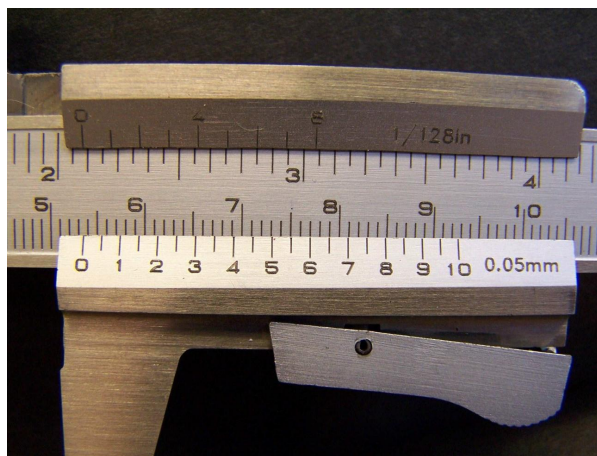
Recording data

- From the WebAssign, right click on the Excel file “youngs_modulus.xls,” and save it to My Documents. Double-click the file to open it in Excel.
- You should see a display that includes places for your group information, measured values, and calculated values, as well as a space for your graph.

- You will record all of your data and analysis on the Excel sheet and submit it to WebAssign to be graded by your TA.

Measuring with Vernier Calipers

In this laboratory exercise you will be using a Vernier caliper, which is comprised of two “teeth”, one attached to a fixed scale and the other attached to a sliding (Vernier) scale. In order to measure an object’s width, the object is simply placed between the caliper’s two teeth. The sliding tooth is then moved until the object is pressed tightly between the teeth. Using both scales, the width can be read to the nearest 0.005 cm (or 0.05 mm). The scales are read as follows (refer to the figure):



(a)

1. Find where the 0 mark of the sliding scale lines up on the fixed scale. In this case, it is just past the 5.3 cm mark. So, the first reading is 5.3 cm.
2. Find the mark on the sliding scale that most closely lines up with one of the marks on the fixed scale. Here, 5.0 and 6.0 are very close, but 5.5 lines up best with one of the marks on the fixed scale. This value is the number of hundredths of centimeters (or tenths of millimeters). So, the second reading is 0.055 cm.

3. Add the two values together to get the total reading: $5.3 \text{ cm} + 0.055 \text{ cm} = 5.355 \text{ cm}$

To get more practice reading calipers, visit the following website which has an interactive Java applet:

<http://physicspmb.ukzn.ac.za/OnlineExercises/Vernier10/Vernier.html>

Note: At this website, the label on the sliding scale is misleading. The scale is labeled “mm”, which leads the user to think that the numbers on that scale represent millimeters. This is **NOT** correct. As described above, the numbers on the sliding scale represent tenths of millimeters.

A.1.5 Measurements

Dimensions of the wire

One of the goals is to describe the “stretchiness” of a material independent of the size and shape of the wire. To do this, we first need to know the physical dimensions of the wire.

Measure the following and enter your data into your Excel sheet:

- Entire length of the wire without any weights on it.
- Diameter of the wire using the caliper (see the Measuring with Vernier Calipers Section)
 - Using the measured diameter of the wire, calculate the cross-sectional area of the wire.

CHECKPOINT: Compare your data with another group to make sure it is reasonable.

Stiffness of the wire

To determine if the straight wire behaves like a spring, you need to measure the position of the end of the wire as you add different amounts of weight.

Remove the kinks in the wire:

- If the wire has kinks in it, you will measure the springiness of the “coiled” wire instead of the stiffness of a straight wire. Remove the kinks before starting your measurements.
 - Add 6 kg to the platform hanging from your wire. Remove the 6 kg. Repeat. This helps get small kinks out of the wire, so the “straight” wire doesn’t act like a coiled spring.

Take the following measurements and record your data in your Excel sheet:

- Look at the scale on the apparatus, and make sure you know what the divisions are, and how to read the scale. You should be able to measure to the nearest 0.1 mm.
- You need to make three sets of measurements, so that you can get average values.
 - Take measurements with 0 kg, then 2 kg, 4kg, 6kg.
 - Take all the masses off and start from zero again, taking the same measurements twice more.
 - Take the average of your three sets of measurements.
- Calculate the variation of your measurement:
 - The variation in the measurements (the “reproducibility”) gives you an indication of how meaningful the individual measurements are. Record your estimate of the variation.
 - * If the measurements are 5.5, 5.7, 5.4, 5.6, 5.8, and 5.6 mm, the average is $(5.5 + 5.7 + 5.4 + 5.6 + 5.8 + 5.6)/6 = 5.6$, from a minimum of 5.4 to a maximum of 5.8.

- * A compact way to report this average with the approximate variation is 5.6 ± 0.2 mm.
- *If the variation is larger than 0.3 mm, you MUST repeat your measurements.*
- * Discard earlier measurements since this was probably getting more kinks out of the wire.

BEFORE graphing your data, discuss the following questions with your group members:

- If the wire acts like a spring, what would you expect a graph of stretch versus force to look like?
- How could you determine the spring stiffness of the wire from the graph?

Use your data to make a graph in Excel of the stretch of the wire (on the y-axis) versus the force exerted on the wire (on the x-axis):

- Both of these quantities will need to be computed from your data (either by hand or using Excel).
- From the two columns representing stretch and force, highlight the cells with the data for 2, 4, 6 kg.
 - **Note:** Do **NOT** include the data for 0 kg, because the wire may be kinked without a load.
- Choose menu option Insert → Chart, and choose ‘XY (Scatter)’. (Do **NOT** choose a ‘Line’ chart).
 - Be sure to verify that you have the proper quantities on the proper axes.
 - Fit your data to a ‘Trendline’:
 - * Right click on one of the data points and select ‘Add Trendline’

- * Choose ‘Linear’ under ‘Type’
- * Under ‘Options,’ choose ‘Display Equation on Chart’ – this will display the equation of the line that best fits your data in the form $y = mx + b$. You can reposition the equation.
- From your data, determine the spring stiffness of the wire.
 - * Since $F = k_s s$, then $s = \frac{1}{k_s} F$, so the slope of your graph is equal to $1/k_s$.

CHECKPOINT: Compare your measurements, calculations, and graph with another group to verify that they are reasonable.

“Stretchiness” of the metal

Calculating Young’s modulus is a way to measure the “springiness” or “stretchiness” of the metal and factor out the size and shape of the particular wire.

BEFORE: calculating Young’s modulus, discuss the following questions with your lab partners and write your answers on a whiteboard:

- If the cross-sectional area of the wire were doubled, would the wire stretch more, less, or the same amount when you hung a 2 kg mass on it? Why?
 - Think about putting two of your original wires together side by side.
 - How does this compare to placing two springs in parallel?
- If the wire were twice as long, would it stretch more, less, or the same amount when you hung a 2 kg mass on it? Why?
 - Think about connecting two of your original wires end-to-end.
 - How does this compare to placing two springs in series?
- The quantity F/A is called “stress”. What are its units?

- The fractional stretch $\Delta L/L_0$ is called “strain”. What are its units?

CHECKPOINT: Compare your responses with another group.

Use the measurements for your wire to determine Young’s modulus:

- At equilibrium $F = k_s \Delta L = s$, so:

$$Y = \frac{(F/A)}{(\Delta L/L_0)} = \frac{(k_s \Delta L/A)}{(\Delta L/L_0)} = \frac{k_s L_0}{A}$$

- Use your measurement for the initial length, your calculated value for the cross-sectional area, and the value for the spring stiffness obtained from your graph to determine Young’s modulus for the material of which your wire is made.
- Show your calculation on your whiteboard and record your result on your Excel sheet.
- How does your value for Young’s modulus compare to that of aluminum ($6.2 \times 10^{10} N/m^2$) or lead ($1.6 \times 10^{10} N/m^2$)? Given that the wire is brass (an alloy of copper and zinc), is your value reasonable?

CHECKPOINT: Compare your results with another group.

Determining the interatomic spring stiffness

Young’s modulus is a way to relate the a macroscopic spring-like properties of the particular metal to the stiffness of that metal’s interatomic bonds (interatomic spring stiffness).

BEFORE: determining the interatomic spring stiffness, discuss the following with your partners:

- Assuming a simple “ball and spring” model for our solid, how could we determine the length of the interatomic bonds if we knew the density of the material? (**Hint:** You have probably done something similar in your homework recently)

- Using this idea and the following information, determine the length of the interatomic bond for brass?
 - Brass is an alloy of copper and zinc.
 - The atomic mass of copper is 64 grams/mole; zinc is 65 grams/mole.
 - The density of copper is 8.94 grams/cm³, for zinc, it is 7.14 grams/cm³.
 - *Note: beware of your units*

Use your calculation of the interatomic bond length and your value for Young's modulus to approximate the stiffness of the interatomic bonds ($k_{s,i}$):

- In the “Stretchiness” of the metal Section, we showed:

$$Y = \frac{k_s L_0}{A}$$

- For our “ball and spring” model, the cross-sectional area of the bond is $A = d^2$ and the relaxed length is $L_0 = d$ (if you are unsure why this is, reread Interatomic Spring Stiffness Section). Thus:

$$Y = \frac{k_s L_0}{A} = \frac{k_{s,i} d}{d^2} = \frac{k_{s,i}}{d}$$

- Show your calculation on your whiteboard and record your result on your Excel sheet.

CHECKPOINT: Compare your results with another group.

Then submit your Excel sheet and answer the follow-up questions in WebAssign.

Bright yellow: original data; Pale yellow: calculated values (and graphs); Blue: cells to use for your graph

Data for straight wire

length of wire (m)	
diameter of wire (m):	
cross-sectional area	

Mass (kg)	Trial 1 Position (mm)	Trial 2 Position (mm)	Trial 3 Position (mm)	Average Position (mm)	Variation (mm)	Applied Force (N)	Average Stretch (m)
0.00							
2.00							
4.00							
6.00							

Calculated values:

Spring stiffness of wire**:		**NOTE: this will come from your graph (see handout)!
Young's modulus:		
Interatomic bond length:		
Interatomic stiffness:		

Graph of Stretch vs. Force with best fit line:

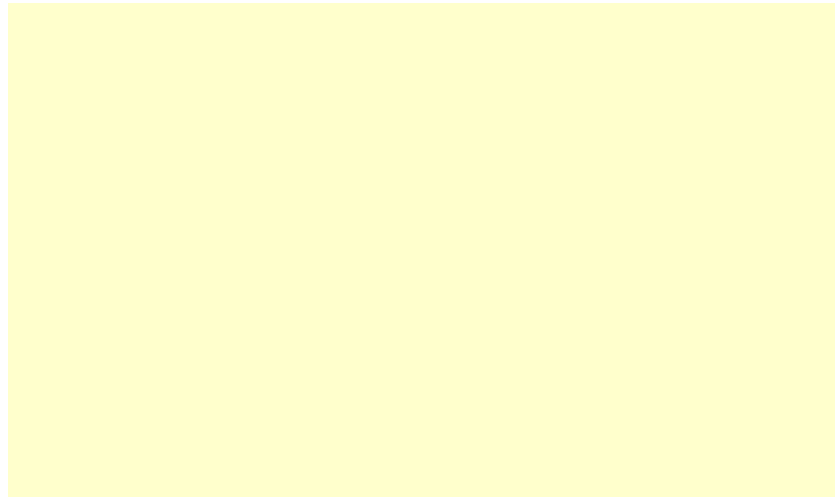


Figure A.1: Young's Modulus Excel Sheet

A.2 Throw a Ball Up in the Air (Ball Toss)

A.2.1 Purpose

In this lab you will analyze the same phenomenon using:

- the Momentum Principle
- and the Energy Principle.

Some useful equations and constants are given at the end of this document.

A.2.2 Experimental Observations

Equipment: tennis ball, 2 meter sticks, stopwatch.

The experiment requires three people.

- One person throws a ball straight up as high as possible, but not so high that it's difficult to measure the maximum height that it reaches. This can be done in an ordinary room, though if you can find a place to throw the ball higher, you'll be able to measure the longer time of flight more accurately.
- The second person starts the stopwatch just after the ball is released and stops it when the ball returns to the height at which it was released.
 - In the approximation that we neglect air resistance, the round trip time is twice the time required to get up to the maximum height. Note that during the round trip time, no one is touching the ball.
- A third person stands off to the side, observes the flight of the ball, and uses a meter stick to determine how high the ball goes from the point where it was released.

Record the round trip time, the time to reach maximum height, and the maximum height for two trials.

CHECKPOINT: Compare your data with another group to make sure it is reasonable.

A.2.3 Analysis of Experimental Observations (on Whiteboards)

Momentum Principle

Using the **Momentum Principle**, use your experimental observations to determine the initial speed.

- **Note:** Do **NOT** use numbers (except for zero) until asked to do so, and be careful of signs.
- Use m for the **mass** of the ball, v for the initial **speed**, and Δt for the **time** to reach the top. Use g to represent $+9.8 \text{ N/kg}$.
- For the **system** of the **ball**, write the **Momentum Principle** for *this specific situation*
 - Initial state: just after the ball leaves your hand
 - Final state: when the ball reached its maximum height
- Solve for an expression for the initial speed, v . (**Note:** expression should have **NO** numbers!)

CHECKPOINT: Compare your results with another group.

- Now use your experimental numbers to predict the initial speed for each of your two trials.
- Show your calculations on your whiteboard.
- Check your units and the reasonableness of your values.
 - **Note:** a professional pitcher can throw a baseball at about 40 m/s (90 mi/hr).

Energy Principle

Using the **Energy Principle**, use your experimental observations to determine the initial speed.

- **Note:** Do **NOT** use numbers (except for zero) until asked to do so, and be careful of signs.
- Use m for the **mass** of the ball, v for the initial **speed**, and Δy for the maximum **height**. Use g to represent $+9.8 \text{ N/kg}$.

- For the **system** of the **ball**, write the **Energy Principle** for *this specific situation*
 - Initial state: just after the ball leaves your hand
 - Final state: when the ball reached its maximum height
- Solve for an expression for the initial speed, v . (*Note:* expression should have **NO** numbers!)

CHECKPOINT: Compare your results with another group.

- Now use your experimental numbers to predict the initial speeds for each of your two trials.
- Show your calculations on your whiteboard.
- Check your units and the reasonableness of your values.

A.2.4 Comparison and Reflection

For each trial, compare the initial speed predicted by part A.2.3 and part A.2.3. Are your results consistent?

Reflection: The momentum principle involves time; the energy principle involves distance.

Look back over your analysis and see how the two principles complement each other, involving different kinds of information about the phenomenon.

CHECKPOINT: Recorder should enter experimental data and results into WebAssign.

Answer the follow-up questions in WebAssign as a group.

WebAssign response cells for this activity:

2. [+ Question Details](#) CS Throw Ball Up Lab Data Entry [658119]

Enter your data and results here. WebAssign cannot check whether or not you have correctly recorded your data, but it can check the calculations you do based on the data you report.

In the table below, enter your data:

	Time Round Trip (sec)	Time One-Way (sec)	Maximum Height (m)
Trial 1	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>
Trial 2	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>	<input style="width: 90%;" type="text"/>

Using the **Momentum Principle**, use your data to calculate the initial speed for each trial:

Trial 1: $v_{\text{initial}} =$ m/sec
 Trial 2: $v_{\text{initial}} =$ m/sec

Using the **Energy Principle**, use your data to calculate the initial speed for each trial:

Trial 1: $v_{\text{initial}} =$ m/sec
 Trial 2: $v_{\text{initial}} =$ m/sec

Figure A.2: Data field and answer boxes for v_i .

A.3 Fission Problem

Images of the Fission problem appear on the following few pages

Figure A.3: Fission Problem Statement includes the problem story, the story diagram (the correct order of events is c, a, b), and the first four questions asked of the students. Focus is on the last of these questions, but may take dialog and interactions concerning the first three questions as they appropriately pertain to the last question.

Fission Problem

For some isotopes of some very heavy nuclei, including nuclei of thorium, uranium, and plutonium, the nucleus will fission (split apart) when it absorbs a slow-moving neutron.

For example, uranium-233, with 92 protons and 141 neutrons, can fission when it absorbs a neutron and becomes uranium-234. The two fission fragments, called "daughter" nuclei, can be almost any two nuclei whose charges Q_1 and Q_2 add up to $92e$ (where e is the charge on a proton), and whose nucleons add up to 236 protons and neutrons (U-234, formed from U-233 plus a neutron).

One of the possible fission modes involves nearly equal fragments, palladium nuclei (Pd-117) each with electric charge $Q_1 = Q_2 = 46e$. The rest masses of the two daughter nuclei add up to less than the rest mass of the original parent nucleus. (In addition to the two main fission fragments there are typically one or more free neutrons in the final state; in your analysis make the simplifying assumption that there are no free neutrons, just two daughter nuclei.)

Objects involved in the reaction:

Nucleus	# of protons	# of neutrons	Charge	Rest Mass (atomic mass units)
U-234	92	142	+92e	233.99
Pd-117	46	71	+46e	118.393

Although in most problems you solve in this course it is adequate to use values of constants rounded to 2 or 3 significant figures, **in this problem you must keep 6 significant figures throughout your calculation.** Problems involving mass changes require many significant figures because the changes in mass are small compared to the total mass. **In this problem you must use the following values of constants, accurate to 6 significant figures:**

<u>Constant</u>	<u>Value to 6 significant figures</u>
c (speed of light).....	2.99792e+08 m/s
e (charge of a proton).....	1.60218e-19 coulomb
atomic mass unit.....	1.66054e-27 kg
$\frac{1}{4\pi\epsilon_0}$	8.98755e+09 N·m ² /C ²

Fission Problem (continued)

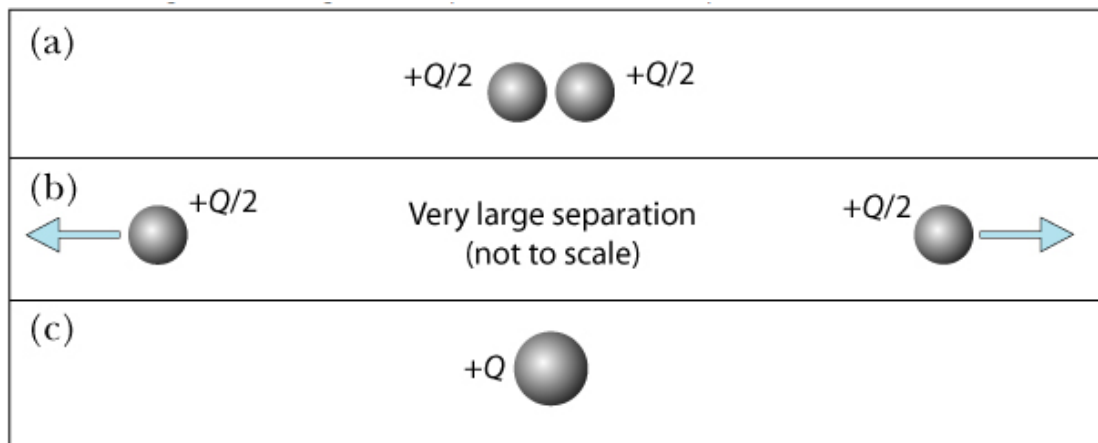
There are three states you should consider in your analysis:

- (1) The initial state of the U-234 nucleus, before it fissions.
- (2) The state just after fission, when the two palladium nuclei are close together, and momentarily at rest.
- (3) The state when the palladium nuclei are very far away from each other, traveling at high speed.

A: The final speed of the fission products

Your first task is to determine the final speed of each of the daughter nuclei in state (3), when they are far from each other.

Here is a diagram showing three important states in the process:



Fission Problem (continued)

Which diagram depicts the state of the original uranium nucleus? We'll take this state to be the initial state.

- a
- b
- c

Which diagram depicts the state when the two daughter nuclei have reached their final speeds? We'll take this state to be the final state.

- c
- b
- a

Compare the initial and final states of the system. Which quantities have changed?

- potential energy
- kinetic energy
- rest energy

What will be the total kinetic energy of the two daughter nuclei when they are very far apart?

$$K_1 + K_2 = \boxed{} \text{ joules}$$

A.4 Spectra Problem

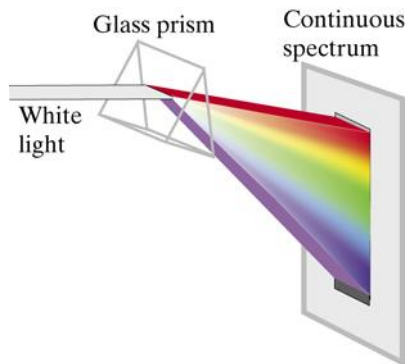
Images of the Spectra problem appear on the following few pages

Figure A.4: Spectra problem statement

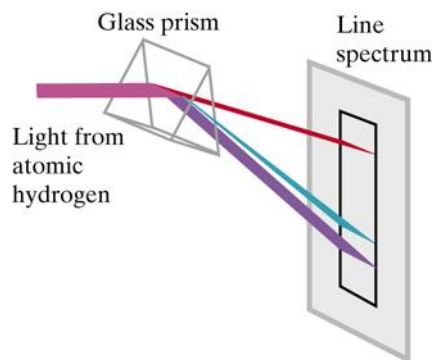
Spectra Problem 1

The average eye is sensitive to photons with energies in the range from 1.8 eV, corresponding to red light, to 3.1 eV, corresponding to violet light. White light is a mixture of all the energies in the visible region.

If you shine white light through a slit onto a glass prism, you can produce a rainbow spectrum on a screen, because the prism bends different colors of light by different amounts.



If you replace the source of white light with an electric-discharge lamp containing excited atomic hydrogen, you will see only a few lines in the spectrum, rather than a continuous rainbow.



The energies of the quantized states in atomic hydrogen are given by $E_N = -\frac{13.6}{N^2}$ eV, where $N = 1, 2, 3, \dots$

Spectra Problem 1 (continued)

Given this, predict how many lines will be seen in the visible spectrum of atomic hydrogen, and specify the atomic transitions that are responsible for these lines.

Fill in the following table, listing the energies of the visible photons emitted in order, from highest to lowest energy. Put zeroes in any remaining boxes.

N of initial state	N of final state	Photon energy
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV
<input type="text"/>	<input type="text"/>	<input type="text"/> eV

Spectra Problem 2

A diatomic molecule such as N_2 can be considered to be a quantized harmonic oscillator, with quantized vibrational energy levels which are evenly spaced.

Estimate the difference in energy between two adjacent vibrational energy levels for a nitrogen molecule. Some of the information you need to do this can be looked up in your book, but you will have to estimate at least one quantity, based on similar quantities you previously calculated. A range of estimates is accepted here:

$$\Delta E \approx \boxed{} \text{ eV}$$

Spectra Problem 3

A diatomic molecule such as N_2 can be considered to be a quantized harmonic oscillator, with quantized vibrational energy levels which are evenly spaced.

Estimate the difference in energy between two adjacent vibrational energy levels for a nitrogen molecule. Some of the information you need to do this can be looked up in your book, but you will have to estimate at least one quantity, based on similar quantities you previously calculated. A range of estimates is accepted here:

$$\Delta E \approx \boxed{} \text{ eV}$$

Based on this estimate, how much energy would be required to raise a nitrogen molecule from its 8th excited vibrational state to its 11th excited vibrational state?

$$\text{energy} = \boxed{} \text{ eV}$$

Appendix B

Coding Task Materials

Note: In these materials I use the term TA instead of GTA. All TAs are in fact GTAs.

B.1 Issue Component Matching Task Materials - Students

Familiarity with the labs and pieces of each problem are important for these tasks. Please review the instructions/questions for the following labs before coding:

- Young's Modulus
- Ball Toss
- Fission
- Spectra

Task 1 (Matching Transcript to Issue Boxes - Students)

Students create issues (errors and uncertainties) while working through a problem solving lab activity. As these issues emerge from the data, we summarize each one in an issue box. Each issue box contains the content of an issue and any supporting information present. We attempt to use dialogue from the transcript directly whenever possible. However, in many cases, we must summarize an issue in our own words, rather than the students'.

Note: Students are not always focused on the same thing as the content of the issue (though they often are). The issue may be revealed to us within the discussion of a different topic, or students intended goal may not match their actions. In these cases, students are not necessarily aware or focused on the issue they've created. **For the purpose of this task, we are NOT concerned with what the students' intent or focus is, but with the actual issue they create.**

For your convenience and to hopefully lessen confusion -

Issue Boxes: In the following task(s), you will be matching pieces of transcript to issue boxes. Issue boxes contain summarized descriptions of issues or focal topics. Each issue box is divided into four sections. They are:

- **Conceptual (C)** - a conceptual idea of either physics or the physical situation, or concerning the interpretation of the problem statement
- **Conceptual Why (CWhy)** - reasoning behind the conceptual idea... this may or may not be content oriented
- **Procedural (P)** - a move to be made during the construction of a solution or concerning the following of specific instructions
- **Procedural Why (PWhy)** - reasoning behind the move... this may or may not be content oriented (this also may be the same as C if the reasoning is conceptual)

0 - 4 of the above pieces of the issue box may be filled in with a description. (0 indicates there is no actual issue arising in the transcript.)

There may not be anything specifically wrong or uncertain with the content in every section of the issue box that contains a description. In some cases, descriptions may be present to offer supporting information to the issue, even if they are not wrong in themselves. There will, however, be something wrong or uncertain in at least one of the boxes (so long as an issue is present at all).

In this task, we are interested in validating these summaries in the issue boxes. Each transcript in this set fits with an issue box. There are twice as many issue boxes as there are transcripts. So you will only use half the issue boxes. Match each piece of transcript with its respective issue box.

It will probably help to do an initial sorting of the boxes into their various topics before beginning the task. There are 100 boxes.

Some guidelines to follow as you do this task: Where you can, match transcripts exactly. In some cases, you will find exact phrases from a transcript in an issue box. This is a good indication of a match, especially if the phrases that match are detailed.

- Details are written in where they exist. If you are trying to decide between two or more boxes for a particular transcript, look at the details given.
- There are a few cases in which the issue box contains slightly more detail than the transcript. When this happens it is for the researcher to identify the problem the students are working on.
- There are a few issue boxes that read very similar to others, but are not actually the same. These boxes will have different numbers on the back. Beware of these, and attempt to use the details in both the transcript and the issue box to make the most accurate match you can. While the boxes may seem “basically the same”, it is valuable to attempt to identify the one that matches most exactly.
- There are a few issue boxes that read the same as the same issue occurs multiple times. It does not matter which one of these boxes you pick for each transcript. Any one will be fine. You can tell which boxes those are as they will carry the same number on the back.
- If different parts of the same transcript seem to apply to more than one issue box (perhaps students are talking about density at one point and area at a later point), try to match whether the students are creating an issue more specifically around one or the other issue box.

- There are a few pairs of transcripts that will read the same except for there will be some additional transcription at the end of one of them. Take the content of this additional transcription into account when matching these transcripts to issue descriptions.
- Blank issue boxes occur when the students are not actually creating an issue before the interaction. There will be no mistake in what they are doing, and they will not show any authentic uncertainty about their actions or ideas.
- Finally, if you find yourself wondering what to pick, wishing you had more context to go off of, or honestly not being able to choose between a few very similar sounding boxes, ask me! In some instances I may be able to provide context to help your decision, or we can talk through what is distressing. I'll let you know if I feel a question is not something I can answer.

B.2 Issue Component Matching Task Materials - TA

Familiarity with the labs and pieces of each problem are important for these tasks. Please review the instructions/questions for the following labs before coding:

- Young's Modulus
- Ball Toss
- Fission
- Spectra

Task 2 (Matching Transcript to Issue Boxes - TA)

For your convenience and to hopefully lessen confusion -

Issue Boxes: In the following task(s), you will be matching pieces of transcript to issue boxes. Issue boxes contain summarized descriptions of issues or focal topics. Each issue box is divided into four sections. They are:

- **Conceptual (C)** - a conceptual idea of either physics or the physical situation, or concerning the interpretation of the problem statement

- **Conceptual Why (CWhy)** - reasoning behind the conceptual idea... this may or may not be content oriented
- **Procedural (P)** - a move to be made during the construction of a solution or concerning the following of specific instructions
- **Procedural Why (PWhy)** - reasoning behind the move... this may or may not be content oriented (this also may be the same as C if the reasoning is conceptual)

0 - 4 of the above pieces of the issue box may be filled in with a description. (0 indicates there is no actual issue arising in the transcript.)

As the TA focuses on specific topics or issues (emergent in the data), we summarize each one in an issue box. We attempt to use dialogue from the transcript directly whenever possible. However, in many cases, we must summarize in our own words, rather than the TA's.

In this task, we are interested in validating these summaries in the issue boxes. Each transcript in this set fits with an issue box. There are twice as many issue boxes as there are transcripts. So you will only use half the issue boxes. Match each piece of transcript with its respective issue box.

It will probably help to do an initial sorting of the boxes into their various topics before beginning the task. There are 100 boxes.

Some guidelines to follow as you do this task:

- We want to know specifically what the TA focuses on. Some boxes may sound more like content the TA might focus on, but the students might not. This is a good indicator that it will fit with one of the data segments.
- Where you can, match transcripts exactly. In some cases, you will find exact phrases from a transcript in an issue box. This is a good indication of a match, especially if the phrases that match are detailed.
- Details are written in where they exist. If you are trying to decide between two or more

boxes for a particular transcript, look at the details given and try to make the most exact match you can with the transcript.

- Sometimes the TA will not speak on a topic so much as just respond to a student (typically, confirmations or negations with no additional discussion fit these). In these cases, the TA is focused on the same thing the student is focused on, and the issue box will follow what the student is saying (and/or doing), rather than the TA.
- There are a few issue boxes that read the same as the same issue may occur multiple times. It does not matter which one of these boxes you pick for each transcript. Any one will be fine. You can tell which boxes those are as they will carry the same number on the back.
- There are a few issue boxes that read very similar to others, but are not actually the same. These boxes will have different numbers on the back. Beware of these, and attempt to use the details in both the transcript and the issue box to make the most accurate match you can.
- Blank issue boxes occur when the TA does not confirm, deny, nor discuss an issue presented by the students.
- Finally, if you find yourself wondering what to pick, wishing you had more context to go off of, or honestly not being able to choose between a few very similar sounding boxes, ask me! In some instances I may be able to provide context to help your decision, or we can talk through what is distressing. I'll let you know if I feel a question is not something I can answer.

B.3 Issue Content Category Sorting Task Materials

Familiarity with the labs and pieces of each problem are important for these tasks. Please review the instructions/questions for the following labs before coding:

- Young's Modulus
- Ball Toss
- Fission
- Spectra

Task 1 (Issue Order)

Here we are interested in looking at the order of the issue the students create. Sort the following pieces of transcript into the order in which they best fit, construction or execution.

Construction issues tend to deal more with the problem as a whole or specific pieces of physics within the solution construct but rarely with the application of numbers or specific finding of answers through calculations. Execution issues deal mostly with applications of numbers (and units) and finding answers through calculations.

Select the order that best fits the transcript (not necessarily what is required by the problem).¹

Note: If a segment seems to have both Construction and Execution (perhaps students construct and then execute), mark it as Construction.

Task 2 (Issue Nature)

Here we are interested, for each issue, which topic best fits. For construction issues, we want to know if they are of the nature of students just beginning a problem, or if they are particular to students' solution approach. For execution issues, we want to know if they are of the nature of unit conversions or something else. Sort the following pieces of transcript into the topic in which they best fit.

Execution

Students' focus more on end-of-solution pieces. Students may or may not be close to finished with the problem, but they are typically dealing with applying numbers or units to their so-

¹This line was added after agreement discussions.

lution, with putting answers into WebAssign, or with singular mathematical steps of their calculation. The application of numbers does not necessarily mean the transcript will contain actual numbers, simply that the focus would be more towards putting in numbers and solving than towards creating the initial solution structure. During this time, students may be making the following moves (out loud or silently), discussing them, or just asking questions about them.

Execution Moves	NOT Execution
selecting values for particular variables and/or constants	working/speaking out an entire physics calculation process.
converting quantities (anything mentioning units or unit conversions)	deciding whether or not to set a term to zero.
calculator calculations	
putting answers into their final spot (WebAssign, Excel, etc.)	
solely determining non-physics formulas (volume, circumference, etc.)	

Construction

Students' focus is on either how to begin a problem or how to construct all or particular pieces of their solution (excluding details of applying numbers, units, and finding answers). This may be expressed either through questions, dialogue, or writing. Students do not necessarily need to speak to be constructing.

Construction Moves

Mentions or questions what to do that is more general to beginning the problem (e.g. phrases like “I don’t know”, or “I have no idea”) Students may be very non-specific if their confusion is high.
Mentions, either through dialogue questions, or writing, use of or ideas about specific physics terms (e.g. RestE, Fgrav, etc.)
selection of physics formulas or a description of how to calculate them
Mentions, either through dialogue or questions, physics concepts or the physical situation
Dialogue or questions around setting terms to zero or how to find particular quantities ²

Conversion

Students either consciously or un-consciously create an issue around converting a particular physical quantity. Look for specific units being mentioned in the transcript: either in dialog or in actions marked by parentheses.

Note: Students do not have to be aware they are creating an issue around unit conversions. Units just have to be a part of the transcript.

Getting Started

Students express not knowing how to begin to solve a problem. This may be seen in a lack of real expression other than confusion. Or they may include a few pieces of information on the problem, but do not really know how to begin.

²“how to find particular quantities” was added after agreement discussions.

Getting Started Behaviors

Mentions or questions how to do something more general to beginning the problem (e.g. phrases like “How do we?”, “I don’t know”, or “I have no idea”) Students may be very non-specific if their confusion is high.

Mentioning asking the TA

Reading and/or re-reading the question/problem statement

Solution Approach

Students are working on constructing a solution, but have trouble with a particular piece of that construction or idea surrounding it.

Solution Approach Moves

Mentions, either through dialogue or questions, use of or ideas about specific physics terms or quantities (e.g. RestE, Fgrav, etc.)

Selection of physics formulas or a description of how to calculate them

Mentions, either through dialogue or questions, physics concepts or the physical situation

Mentions problem statement details that don’t have to do with the application of numbers (Exception: setting terms to zero)

B.4 Characteristics of the Interaction Sorting Task Materials

Transcript Key: The transcript covers the TA’s presence with the group of students or presence and summoning (if there is a “(hand up)” description prior to the interaction). The following have been marked for clarity and coding purposes:

1. Interaction Lines - A short horizontal line labeled with an “i” marks the beginning and end of an interaction between students and the TA.

2. Diagnosis Sections - The section highlighted in pink is the diagnosis section. Pink sections will be coded in task three and may serve as context for other tasks. Note: If an interaction line is placed within or after a pink section, the TA has been observing students prior to the start of the interaction.
3. Post Diagnosis Sections - The section highlighted in blue is post-diagnosis section. Blue sections will be coded in tasks 4-8 and may serve as context for task 3.

If you are uncertain what to code based on the rules in any task, step back, attempt to answer holistically, and check with the video.

Task 1 (Diagnosis):

Here we are interested in how the TA comes to discuss the chosen topic. In other words, how he/she diagnoses the situation.

Sort the following transcripts into how the TA diagnosed the situation. The diagnosis section is highlighted in pink. Reading through that section, decide if the TA makes a diagnosis Actively, Passively by Listening, Passively by Reviewing Work, or Abbreviated. Also look at what the TA says in the blue highlighted section to see if they are paying attention to student talk or student work

Note1: There may be more than one diagnosis method used. If that is the case, **select the highest listed method that occurs**. For instance, if the students are describing what they are doing out loud as they do it, and the TA is present to hear it, the TA may be both listening to their description and looking over their work. Mark L for this, as the higher listed diagnosis method is L (over W).

Note2: In all the following, one or more students may hold the TA's attention (or none, if the TA is focused only on their work). Look to the student(s) the TA pays attention to to help determine the TA's method of diagnosis. Any students to whom the TA is not paying attention do not count here.

Task 2 (Who Directed):

Here we are interested in who directed the dialogue after the diagnosis occurred. Looking specifically at the dialogue in the blue highlighted section (but possibly guided by dialogue beforehand), sort the following transcripts into who directed the dialogue, the students or the TA.

Take a look at the dialogue as a whole and determine as best you can, very basically, who is controlling its direction and flow in the marked section. While sorting, think about the answers to the following:

- Are the students participating in a TA controlled dialogue?
- Or is the TA participating in student controlled dialogue?

Note2: In all the following, one or more students may hold the TA's attention. Look to the student(s) the TA pays attention to, and use those student(s) to determine whether or not they direct conversation. Any students to whom the TA is not paying attention do not count here.

Task 3 (How Students Directed):

Here we are interested in how the students directed the dialogue. Looking specifically at the dialogue in the blue highlighted section (but possibly guided by dialogue beforehand), sort the following transcripts into how the students directed the dialogue, through questions, sharing, or disengaging.

Task 4 (How TA Directed):

Here we are interested in how the TA directed the dialogue. Looking specifically at the dialogue in the blue highlighted section, sort the following transcripts into how the TA directed the dialogue, through seeking student input, or not seeking student input.

Task 5 (Do Students Share Ideas):

We are interested in knowing whether the students, at any time, share their own ideas during

TA directed dialogue. Looking specifically at the dialogue in the blue highlighted section, sort the following transcripts as to whether or not the students share their ideas.

The student talk might be short in length, but look for an authentic sharing of ideas.

Task 6 (How Do Students Share Ideas):

We are interested in knowing what spurred students to share their ideas. Looking at the dialogue just before students share their ideas, were they prompted by the TA to do so, or did they share of their own accord?

Look generally for what seems to spur the students to share their ideas. If the TA encourages them to do so in anyway, then they are prompted by the TA. If there is no push from the TA, but the students share regardless, they are doing so of their own accord.

Actively (1)

The **TA guides** the students to verbalize their situation. This includes asking **probing** questions of the group (typically multiple questions); **directing** students to describe and/or explain their ideas or process; or **repeating** students' ideas back to them. If both the TA and students are **working together** to find a mistake, this is also active.

Listening (2)

The TA listens to students talk amongst themselves or talk to the TA to figure out what the students have done/thought. The focus here is on the students getting their thoughts and/or processes out while the TA gathers information through the students verbalizations. There may be questions within the students' thoughts, but **the focus is on the students' thoughts/processes**. The TA must allow time for the idea or process to be expressed to the satisfaction of the students. In the case that students are not sure what their ideas or processes

are, there may be more silence involved. The TA must allow time for this silence to the identify that the students have no more to share.

Listening Behaviors	NOT Listening
TA stands behind students as they talk to each other or themselves before an interaction begins	If students ask a question that contains an idea (but the focus is on the question) or simply asks a question, and the TA immediately begins answering in some way. This should get Abbreviated.
Students begin the interaction by explaining their idea or process. There may be questions involved.	If the students attempt to share an idea or process but are cut off by the TA before the majority is shared (as the TA isn't really listening to their idea). This should get Abbreviated
The TA asks a question, and the students do more than just answer the question, giving a full idea or process with their answer.	If the TA listens before the interaction, but can't gather much information, so asks a question that is answered briefly, and then begins addressing the response.
Students confirm the correctness of an idea by sharing it verbally or working it out on the WB in front of the TA (does not count for sharing numerical answers)	

Reviewing Students' Work (3)

The TA looks over students' **whiteboard work, calculator work, or PC work/answers** to figure out what the students have done/thought. This may be done silently or out loud by the TA (TA describes what he/she is seeing on the whiteboard). This may happen before, or during (beginning or middle) an interaction.

Reviewing Student Work Behaviors

If the TA brings up a topic that was seemingly not a part of the previous verbal dialogue, then the TA was probably examining the whiteboard just beforehand.

The TA only acts in response to students' numerical answer, spoken or written/typed.

Abbreviated (4)

If a diagnosis is abbreviated, there has not been sufficient time to really assess what might need attending, and there has been no extra effort made by the TA to get more information on what might need attending. Brief questions and answers between the students and the TA are the most typical kind of abbreviated diagnoses.

Abbreviated Behaviors

Students ask a question (there may or may not be a full idea or reasoning with their question), and the TA begins immediately addressing the student's question instead of probing further or allowing time for the students to keep talking. Note: the topic the TA begins with may or may not seem to match the question asked.

The TA cuts the students off partway through a question, answer, or idea to begin responding to it (however, if the cutoff is apparently due to the TA examining the WB work and finding something, mark Reviewing Work. This should be indicated in what the TA says. If the cutoff seems to be towards the end of that idea, mark Listening).

The TA asks a question. The students answer the question and do no more than that, and the TA begins addressing the situation.

Students seem unsure what to do or say and there is some amount of silence on their part, possibly mixed with brief verbalizations of their confusion. The TA does not probe or allow much time for any silence to see if more will be expressed, but he/she begins addressing their confusion immediately.

Directed By Students

For dialogue to be directed by students, the students will generally control the flow and direction of conversation either through their statements or their questions. (Note: In all the following, one or more students may hold the TA's attention. Look to the student(s) the TA pays attention to, and use those student(s) to determine whether or not they direct conversation. Any students to whom the TA is not paying attention do not count here.)

Directed by Students Behaviors	NOT Direct by Students
Students control the topic and flow of the conversation. The TA may try to help in his/her own way, but is essentially participating in student led conversation. The students may have more assertive body language and tone of voice.	Students sharing their ideas if they are not directing the topic or flow of conversation
The TA directly and explicitly answers students' questions without adding more. (Students' question may appear in the pink highlighted section) Specifically, the TA does not attempt to choose a topic or strategy to help students and direct them through. He/she simply addresses the students' questions.	Students having epiphanies or correcting their mistakes from their own realizations if they are not also directing the topic or flow of the conversation
The student(s) and TA work together towards something (that neither of them knows).	Students ignore the TA momentarily to correct something and then re-engage with the TA
Students ignore the TA and continue working	

Directed by the TA

For dialogue to be directed by the TA, the TA controls the topic and flow of conversation. Students may participate in the conversation - may answer questions and/or share their ideas - but the TA is guiding the the course of the dialogue.

Directed by the TA Behaviors

The TA talks most of the time, with or without student contributions (If students participate, they follow the TA's lead in dialogue, either answering his/her questions, nodding along with "okays", or inserting their ideas.)

TA answers students questions but does not really stop there and continues explaining or directing beyond that, taking the flow into his/her own hands

The TA refocuses students' attention. This may be more typical of shorter dialogues in which the TA is correcting, or trying to get students to adjust what they're thinking or looking at.

Question Directed

The students have asked one or more questions of the TA, but do not include any of their own ideas within those questions. (These questions may occur above, in the pink highlighted section)

Sharing Directed

The students talk about what they think and share their own ideas and processes. This is what guides the flow of the conversation.

Sharing	NOT Sharing
Ideas may be shared through questions	
Asking if an idea is correct, can be sharing an idea	Asking if an answer is correct is not sharing an idea
The students share ideas/processes as they and the TA equally direct the dialogue, typically as a collective effort towards something	

Disengagement Directed

The students will largely ignore the TA and do their own thing. The TA may continue talking here, but the students are not really following the TA.

Seeks Student Input

The TA guides or directs students to give input through his/her actions towards the student.

Seeks Student Input Behaviors	Does NOT Seek Student Input
purposeful pauses - TA talks and leaves a piece out for the students to fill in, or pauses with the intent (in tone of voice or choice of words) for the students to talk (video might be important for interpretation of expectant pause vs just silent space)	The TA does not purposefully ask questions, leave space, leave blanks, or in any way request student input during this part. (Note: This does NOT mean that the students don't talk or give their input at all. It simply means it is not actively encouraged in any way by the TA.)
open or probing questions (often "how" or "why" questions)	The TA asks rhetorical questions
closed or targeted questions (asking for answers instead of thoughts)	The TA asks for agreement from students (Talk ending in "right?" should not count as seeking student input.)
actual directions to do something during the interaction so to watch them. (e.g. TA requests students do a calculation in front of him/her)	TA asks questions to ensure students are set up to move on with their solution
	Students cut off the TA to express a thought

There may be a lot of TA talk/explanation or correction surrounding each moment. We are just looking to see if those moments exist at all.

Students Share Ideas

There are a many student expressions that might seem like sharing an idea. When you find one that seems like sharing, make sure you check the “NOT sharing Ideas” list before finalizing your decision.

Sharing Ideas Behaviors	NOT Sharing Ideas
Students will share what they think , not just what they think the TA is asking of them. This might be different and often above and beyond what the TA might ask of them to contribute.	Answering a TA’s question without additional reasoning, even if the answer is creative
Students share an idea in agreement with TA. The TA shares a small bit of info or correction and a student shares an idea they had as it fits what the TA is getting at.	Students asking a question if there is no reasoning given surrounding it
Students share an idea without being prompted to do so. They may have figured out where they had erred in their solution (look for “aha” type emotions), or they just decide to share their reasoning.	Students clarifying or synthesizing what the TA is saying (Look around, even outside the marked region for places the TA might have given an idea that a student later synthesizes)
Students respond to probing TA questions, typically “why” and sometimes “how” questions at any time.	Students sharing as a guess at what the TA might want to hear.
	Students extracting a process from a TA explanation. (e.g. “So we do this here?”)
	Students fixing mistakes or constructing solutions, talking through procedures
	A student talking to himself/herself is not sharing as he/she is not sharing to the group or TA

TA Prompted Sharing

Probing questions by the TA (“How?”, “Why?”) to get at how or why students thought or did something with their solution construction.

Purposeful silence left by the TA as space for students to share. Purposeful silence can be preceded by a slowing of the last few words of TA speech and is typically accompanied by encouraging facial expressions and/or the TA leaning in a bit to encourage student sharing. **Note:** If the student begins talking before or in the same timestamp as the TA ends talking, there is typically not enough of a pause to be purposeful. However, in the case of longer silence between the TA talking and students talking, check the video to see whether the silence was purposeful or not.

Own Accord Sharing

There is no purposeful, explicit prompting or silent space by the TA, but students are sharing their ideas anyway. The TA may allow space for that sharing, but does not necessarily create the space before sharing begins.

B.5 Issues Features Coding: Survey

B.5.1 Coding Instructions

Purpose:

By examining this data, we are trying to learn more about interactions between students and their TA:

1. Before: what the students do that leads to an interaction,
2. During: what the students and TA focus on during their interaction, and
3. After: what the students do after that interaction and whether they do anything with information discussed during that interaction.

We find that most TA-student interactions focus on issues the students are having in constructing solutions to a problem. Therefore, we approach examining what the students do and the interaction by focusing on the creation and addressing of the issues students have.

In order to examine the issues, we've developed a survey that guides the coder through the creation of the issue (before), how the issue is dealt with during the interaction (during), and post-interaction actions the students may perform (after).

We'll first brief the coder on Issues, and then give some instructions for taking the survey.

What are Issues?

Issues are errors and uncertainties students create as they construct their solution to a problem that impedes their ability to complete the solution. Issues are the main basis on which interactions between the TA and students focus, and thus become central to the relationship between the TA-student interaction and what the students do before, during, and after the interaction.

We focus on 3 types of Issues throughout our coding:

- **Actual Issue:** the root error or uncertainty that requires resolving as seen by the researcher/physics expert.
- **SPerceived Issue:** the issue students think they have.
- **TAFocused Issue:** the issue the TA addresses during the interaction.

For each type of issue, we identify 4 possible components (for examples of each component, see the following sheets):

- **Conceptual (C):** a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement
- **Conceptual Why (CWhy):** reasoning behind the conceptual idea

- Procedural (P): a move to be made during the construction of a solution or concerning the following of specific instructions
- Procedural Why (PWhy): reasoning behind the procedural move
 - Note: Procedural Why and Conceptual can be the same thing as often (but not always) the motivation for a move is a conceptual idea.

Note: While issues as a whole are defined as errors and uncertainties, each individual component of an issue may or may not be contain elements of error and uncertainty.

Who creates Issues?

While mutple students may give input to the development of the Actual Issue and the SPerceived Issue, typically a single student stands out as the creator of each issue.

Actual Issue: The Actual Issue creator is often (but not always) a more dominant member of the group. In each case, the column header (S1, S2, S3) of the Actual Issue creator will be highlighted in orange in the transcript, and survey questions that pertain solely to the Actual Issue creator will be noted as such in the survey. If more than one student created the Actual Issue, multiple column headers will be highlighted orange, and questions pertaining to the Actual Issue creator should be targeted toward the general consensus (explicit or implicit) of the multiple creators.

SPerceived Issue: The SPerceived Issue is created by the same student who creates the Actual Issue, except in two kinds of cases:

1. If the Actual Issue creator does not perceive an issue at all, but another group member does perceive an issue and resolves the issue, then that other student is the creator of the SPerceived Issue. (In these rare cases, the SPerceived Issue creator header (S1, S2, S3) will be highlighted in purple.)

2. If no group member perceives an issue, then there is no creator of an SPerceived Issue, and no Sperceived Issue exists.

TAFocused Issue: This is created by the TA.

How to take the Survey:

Review the data for the Issue you are coding. The data for each issue is on the subsequent excel sheets and in the video. There are three parts to the data:

(1) Issues Table: Review the diagram next to the transcript. The content of the issue is written out for each type of issue and each component of an issue. This is the issue content developed by the students and TA through their actions and dialogue. (Note: I recognize that some of the dialogue may be representative of more than one issue. Since we will only examine one issue at a time, use the content descriptions given in the diagram to analyze the dialogue.) Blank boxes indicate no observable mention of that component of the issue. Use this table to guide your analysis of the transcript as you answer questions in the survey. (Note on interpreting boxes: If the content written in the boxes for the SPerceived Issue is different from that of the Actual Issue, assume the Actual issue creator has no realization of the content of the Actual Issue at all. Answer questions pertaining to the Actual Issue under this assumption.)

(2) Transcript: Review the dialogue the students and TA create throughout each issue. You may notice that some of the timestamps skip time (highlighted in yellow). This is because of the pieces of transcript I chose to include. I've included transcript that primarily has to do with the issue. I've also included context-giving pieces (or pieces that, if removed, could cause more confusion). And I've included some post-interaction transcript that may or may not pertain directly to the issue, but provides an understanding of how the students respond once the interaction ends. Keep this in mind as you watch video segments as you may have to skip around

a bit in the video to catch all relevant pieces. All relevant (to the issue and survey questions) dialogue is highlighted in blue, while extra dialogue is not highlighted.

Transcription Color Key:

Orange - the Actual Issue creator

Purple - the SPerceived Issue creator (if different from the Actual Issue creator)

Yellow - skips in timestamps (preceded by an empty dotted row)

Gray - the interaction period

Blue - dialogue relevant to the issue and to more general survey questions (Some post-interaction dialogue that does not pertain directly to the issue may still be highlighted blue as it is relevant to specific survey questions.)

unfilled dialogue - dialogue that is not relevant to the issue or survey questions but is included for completeness

(3) Video: Watch all parts that pertain to the given issue, using the timestamps in the transcript to guide you. The video will include movements, body language, tones of voice, facial expressions, and writing that may not be present in the transcript.

Open the survey and review the introduction page. This page will point out the different features of the survey. The survey is designed so that you look at one question at a time. As you move through the different sections of the survey, you will be guided to answer questions about each type of issue and each component of the issue. Though the questions will target the Issue at specific times (before, during, and after an interaction), you may have to look through the entire transcription in order to best answer individual questions. Definitions and any further instructions for particular questions will be written into the questions themselves.

You can go back to previous questions to review or change your answers via one of two ways:

1. Click the back button

2. Return to the Table of Contents by clicking the ToC button next to the next button. From there you can select which block to enter to return to a question. You will be sent to the first question in that block and must click through to the question you want to review.

When you finish the survey, your results will be stored. You will be prompted to start anew with another data set, and you will be taken to the beginning of the new survey. Only begin again with another data set if we have discussed and okayed it ahead of time.

Time	TA	Speech			Key:	Actual Issue creator	SPerceived Issue creator	skipped timestamp	interaction period	relevant dialogue	writing irrelevant dialogue
		S1	S2	S3							
1:25:04				how would you find mass of each of the?							
1:25:05											
1:25:06											
1:25:07				wait							
1:25:08											
1:25:09		(pointing) I mean there's the		uhohhh							
1:25:10		(pointing) Rest mass right there									
1:25:11		(pointing) of each of the 2									
1:25:12		(pointing) (undetectable)									
1:25:13											
1:25:14				so would you divided by the speed of light because rest							
1:25:15				Oh wait no nevermind I don't know (laughter)							
1:25:16											
1:25:17											
1:25:18											
1:25:19											
1:25:20											
1:25:21											
1:25:22											
1:25:23		yeah that's									
1:25:24											
1:25:25											
1:25:26											
1:25:27		(undetectable)									
1:25:28		(undetectable) mass									
1:25:29											
1:25:30											
1:28:13		but how do we find the m c squared? like the final m c squared since we don't have-									
1:28:14											
1:28:15				is the rest mass just the plain mass of the?							
1:28:16											
1:28:17											
1:28:18		almost									
1:28:19											
1:28:20		is it divided by the sss-									
1:28:21		rest mass									
1:28:22		what's the unit for this mass?									
1:28:23											
1:28:24											
1:28:25											
1:28:26											
1:28:27				I have no idea							
1:28:28											
1:28:29		m c squared um									
1:28:30											
1:28:31		at the end this is in (mouse)									
1:28:32		parentheses (mouse)									
1:28:33		then oh		atomic mass units							
1:28:34		atomic mass units									

C	Actual Issue	CWhy
P	How to calculate the rest mass	PWhy

C	SPerceived Issue	CWhy
P	How to calculate the rest mass	PWhy

C	TAFocused Issue	CWhy
P	How to calculate the rest mass via unit analysis	PWhy

Figure B.1: Part of a data segment to be coded using the survey. Transcription from the raw data is on the left while a description of the Issue is on the right.

B.5.2 Survey Format

Each page of the actual survey in Qualtrics looks like Figure B.2. Below, all questions and information from those pages are presented in outline format.

The survey content in the next section is formatted in the following way:

- Chapter Name (e.g. Actual Issue Pre-Interaction) - General Definition



Figure B.2: A sample survey question as it appears to the coder. The survey section headings are on the far left. The current section title, survey question, and possible responses are in the green box in the middle. Examples are below the box, and question instructions and definitions are on the far right.

- Question Number and Question Content
 - * Possible Answers
 - * Instructions
 - Minor Rule Additions or *major redefining of question*
 - * Examples
 - * Framework Feature coded for (e.g., Au for Automatically created, Co for Constructive, etc.)

B.5.3 The Survey

- **Actual Issue Pre-Interaction** - The Actual Issue is the root error or uncertainty that requires resolving as seen by the researcher/physics expert.
 - **Q2.1** - The Actual Issue is the root error or uncertainty that requires resolving as

seen by the researcher/physics expert.

The following questions concern the Actual Issue leading up to an interaction between students and the TA.

* **Feature** - AI

- **Q2.2** - Follow the table on your Excel sheet (sample table below) and mark which components of the Actual Issue are present. (Possible responses: C, CWhy, P, and PWhy)

* **Possible Answers** - multiple select: C, CWhy, P, PWhy

* **Instructions** -

Each Issue consists of 4 possible components:

Conceptual (C) - a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement

Conceptual Why (CWhy) - reasoning behind the conceptual idea, this may or may not be content oriented

Procedural (P) - a move to be made during the construction of a solution or concerning the following of specific instructions

Procedural Why (PWhy) - reasoning behind the move, this may or may not be content oriented (Note: PWhy and C can be the same thing as often (but not always) the motivation for a move is a conceptual idea.)

* **Feature** - AI Components

- **Q2.3** - Is PWhy the same as C in this case?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the content of those boxes is identical.

Mark “No” if the content of those boxes is different.

* **Feature** - AI Components

- **Q2.4** - The following questions concern the creation of the Actual issue as a whole.

Use the table, transcription and video to answer these questions.

* **Feature** - AI

- **Q2.5** - Was the issue created more thoughtfully or more automatically?

* **Possible Answers** - Thoughtfully or Automatically

* **Instructions** -

Mark “Thoughtfully” if the issue was discussed in any way among students, or if the issue creator gave any indication of questioning or thinking through something (verbally or quietly) in creating the issue. (However, simply writing down a formula and moving on does not qualify as thoughtful creation.)

Mark “Automatically” if the students do not notice that they’ve created this Actual Issue. (Like simply writing down a formula or expressing an idea and moving on.)

Note: The students do not need to be aware that there is an issue to construct one thoughtfully or automatically. This only concerns how their ideas and procedures were put together.

· **Minor Rule Additions** -

- (1) If the Issue concerns students getting started on a problem, students must express one complete idea concerning that problem, before asking the TA for help, to be coded as *Thoughtfully*.

(2) If students are selecting data they've taken and inserting it into a pre-determined formula, code as *Automatically* unless they provide other evidence that they are doing more than copying and pasting.

(3) If students have some Automatic tendencies and some Thoughtful tendencies during the creation of the issue, default to coding *Thoughtfully*.

* **Feature** - Au

– **Q2.6** - Did the issue creating student pose the issue as a question?

* **Possible Answers** - Yes or No

* **Instructions** -

Since the issue was created thoughtfully, we'd like to know a little more about how it was constructed.

Mark "Yes" if the issue creator began the issue by asking a question (either rhetorical or to the group).

Mark "No" if the issue creator began constructing the issue in any way other than asking a question.

(e.g. "How does that work?" should get a Yes, while, "I wonder how that works." should get a No.)

Note: The students do not need to be aware that there is an issue to construct one starting with a question. This only concerns how their ideas and procedures were put together.

* **Example(s)** -

As the opening line in the creation of an issue only, the issue creator asks a question like:

“How would we find velocity?”

“Does rest energy change?”

“Could we use this (pointing to formula) to find it?”

* **Feature** - Qa,n-a

- **Q2.8** - Since the issue creating student posed the issue as a question, mark yes below if any student responded to the issue creators question.

* **Possible Answers** - Yes or No

* **Instructions** -

Since the issue was created thoughtfully, we’d like to know a little more about how it was constructed.

Mark “Yes” if the issue creator began the issue by asking a question (either rhetorical or to the group).

Mark “No” if the issue creator began constructing the issue in any way other than asking a question.

(e.g. “How does that work?” should get a Yes, while, “I wonder how that works.” should get a No.)

Note: The students do not need to be aware that there is an issue to construct one starting with a question. This only concerns how their ideas and procedures were put together.

* **Feature** - Qa,n-a

- **Q2.9** - Did the student create the issue (silently or out loud) without any input from other students?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the issue and supporting information was created solely by the student without any input or influence from other students.

Mark “No” if other students gave any input or influenced the issue creator in any way.

Note: The students do not need to be aware that there is an issue to construct one in this way. This only concerns how their ideas and procedures were put together.

* **Example(s)** -

Issue creator sits quietly in between utterances, indicating conscious construction of an idea

Issue creator searches quietly in a book or the computer, indicating a desire to get information to fit an idea

Issue creator talks aloud (either to self or others) his/her ideas, and no one responds

* **Feature** - In

– **Q2.10** - Did one or more students collaborate with the issue creator to construct the issue?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if other students added in specific information to help construct the same move or idea the issue creator is constructing (not oppose it). This could happen if students were conversing together about an idea, or if other students were answering the issue creator’s question.

Mark “No” if other students did not add specific information with their input. This would be the case if other students ask questions of the issue creator, or if students are specifically challenging each others’ ideas.

Note: The students do not need to be aware that there is an issue to construct one through collaboration. This only concerns how their ideas and procedures were put together.

* **Example(s)** -

S1: “We need to find momentum here.”

S2: “Well, there’s mass of the block. That’s given here.”

S3: “And its velocity. We can get that from the graph.”

S1: “So we’ll do $m \cdot v$ using those numbers.”

* **Feature** - Co

– **Q2.11** - Did one or more students challenge the issue?

* **Possible Answers** - Yes or No

* **Instructions** -

Challenges to an issue are typically delivered more aggressively than inquiries or cooperative discussions. They can be in the form of statements or questions, and often are directed at the correctness of particular thoughts or ideas. (e.g. “How does that make any sense?” or “That doesn’t make sense because... [said aggressively]” is a challenge. “Can you explain that to me?” is an inquiry.)

Mark “Yes” if any student challenged a thought or idea concerning the issue.

Mark “No” if no student challenged a thought or idea concerning the issue.

- **Minor Rule Additions** - A Challenge must include one of the following three things: (1) an elevated level of aggression toward the idea, (2) aggres-

sion accompanied by a defense of the idea by the student being challenged, or (3) persistence on the part of the challenger and the student being challenged to hold their ground even if aggression is low.

* **Example(s)** -

S1: "I think v is 0 at the bottom."

S2: "No way. That's when it's about to hit. It has to still be moving."

S1: "Maybe we should be using this other formula instead."

S2: "But that makes no sense. The other formula doesn't have the variables that we have numbers for."

* **Feature** - Ch

- **Q2.12** - Did one or more students ask a non-challenging/inquiring question regarding the issue (even if only for a repeat of information)?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark "Yes" if any student asked an inquiring question concerning the issue. The question may be to learn more about the issue creator's thoughts or to ask for repetition or clarification of a thought.

Mark "No" if no questions concerning the issue were asked, or if the kind of questions asked were not of an inquiring nature. For instance, questions designed to challenge thoughts or ideas should not be included here.

Note: The students do not need to be aware that there is an issue to ask questions concerning one. We want to know if they ask a question within the topic of the issue, not about there being an issue.

· **Minor Rule Additions** -

(1) Questions concerning looking up information or administrative tasks within the activity do not get coded.

(2) In the case of multiple issue creators, any question asked that does not officially generate the issue should be counted regardless of who asked the question.

* **Example(s)** -

S1: "I think we should use the momentum principle."

S2: "What would F_{net} be?"

S1: "Rest energy should stay the same, right?"

S2: "Do the rest masses change?"

S1: "We don't need to use rest energy?"

S2: "Wait, we do or do not use rest energy?"

S1: "Do not."

* **Feature** - Qi

- **Q2.13** - Now we'll examine each component (C, CWhy, P, PWhy) of the Actual Issue separately. Continue using the video, table, and transcript to answer these questions.

- **Characteristics of the Actual Issue** - The Actual Issue is the root error or uncertainty that requires resolving.

- **Q3.1** - Does the issue creator express an element of Uncertainty with this component? (C, CWhy, P, PWhy)

- * **Possible Answers** - multiple select: C, CWhy, P, PWhy

- * **Instructions** -

- Mark "Yes" if the issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Mark “No” if the issue creator seems confident about this component of the issue.

· **Minor Rule Additions for 3.1(P)** -

(1) If an issue creator does not consider changing a move or reflecting on a move when questioned by another group member, there is *no Uncertainty*.

(2) If an issue creator is uncertain initially but seems to become certain by the time an interaction starts, still default to coding *Uncertainty*.

* **Example(s)** -

(C, CWhy, PWhy) “Um, I think it’s because of this, but I’m not sure.”

(P) “Um, I think we use this, but I’m not sure.”

”um, Fnet... graaaaaaavity?”

* **Feature** - U

– **Q3.2** - Is there an element of Error with this component? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the issue creator settles on a procedural move or a conceptual idea that is incorrect in some way.

Mark “No” if the issue creator settles on a procedural move or conceptual idea that is correct.

· **Minor Rule Additions for 3.2(P)** -

(1) Students do not create an Error until they actually make a move. If students have an incorrect idea about what to do but have not made a move, code *no Error*.

(2) If students know they are in Error, but have not specifically made a move

to fix that, code as *Error*.

* **Feature** - E

- **Q3.3** - Has this component been resolved prior to any interaction with the TA? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if this component of the issue is no longer an issue, the resolution is correct, and there is no element of observable uncertainty remaining for the issue creator.

Mark “No” if this component of the issue remains unresolved, is resolved incorrectly, or is resolved correctly, but the issue creator still carries some uncertainty about the issue.

* **Feature** - R

- **SPerceived Issue Pre-Interaction** - The SPerceived Issue is the issue students think they have. This can be the same or different from the Actual Issue.

- **Q4.2** - Check your SPerceived table. Do the students perceive an issue?

* **Possible Answers** - Yes or No

* **Instructions** -

Sometimes students create an issue for themselves and are unaware they have done so.

Mark “Yes” if there is content written in any SPerceived component box.

Mark “No” if all four component boxes are blank.

* **Feature** - SPI

– **Q4.3** - Check your tables for Actual and SPerceived. Is the SPerceived Issue the same as the Actual Issue?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the contents of the SPerceived Issue are the same as the Actual Issue in all boxes.

Mark “No” if the contents of the SPerceived Issue are different in any of the boxes.

* **Feature** - SPI

– **Q4.4** - Follow your table and mark which components are present in the SPerceived Issue. (Please select all that apply: C, CWhy, P, PWhy)

* **Possible Answers** - multiple select: C, CWhy, P, PWhy

* **Instructions** -

Each Issue consists of 4 possible components:

Conceptual (C) - a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement

Conceptual Why (CWhy) - reasoning behind the conceptual idea, this may or may not be content oriented

Procedural (P) - a move to be made during the construction of a solution or concerning the following of specific instructions

Procedural Why (PWhy) - reasoning behind the move, this may or may not be content oriented (Note: PWhy and C can be the same thing as often (but not

always) the motivation for a move is a conceptual idea.)

* **Feature** - SPI Components

– **Q4.5** - Is PWhy the same as C in this case?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the content of those boxes is identical.

Mark “No” if the content of those boxes is different.

* **Feature** - SPI Components

– **Q4.6** - Now, examine each component (C, CWhy, P, PWhy) of the SPerceived Issue. Use the table, transcription and video to answer these questions. (Note: When a question concerns this issue creator, it is referencing the creator of the SPerceived Issue, whose heading is colored purple in the transcript if different from the creator of the Actual Issue. Otherwise the this issue creator is the same as the Actual Issue creator.)

* **Feature** - SPI

• **Characteristics of the SPerceived Issue** - The SPerceived Issue is the issue students think they have. This can be the same or different from the Actual Issue.

– **Q5.1** - Does this component have an element of Uncertainty to it? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if this issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Mark “No” if this issue creator seems confident about this component of the issue.

- **Minor Rule Additions for 5.1(P)** - If an issue creator is confident in his or her ideas and moves, and other students ask intuitive questions, code as *no Uncertainty*.

* **Example(s)** -

(C, CWhy, PWhy) “Um, I think it’s because of this, but I’m not sure.”

(P) “Um, I think we use this equation, but I’m not sure.”

(C, CWhy, PWhy) “F is negative ’cause it’s for... graaaaaaavity? I don’t know.”

(P) “F is negative... maybe? I don’t know.”

* **Feature** - U

- **Q5.2** - Is the issue creator aware of any element of error in this component of the issue? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” only if this issue creator expresses that there might be an error with this component. (e.g. “We must be wrong here....”)

Mark “No” if this issue creator does not express that there might be a possible error.

- **Minor Rule Additions for Q5.2(P)** -

(1) In cases where students use the word “but” to contradict one idea against another, in cases where the seemingly incorrect idea in that contradiction concerns a specific piece of the Issue, code *Error*.

(2) If one student specifically tells another student his or her idea about the issue is incorrect, code *Error*.

* **Example(s)** -

'We thought it was 0 because of this, but we must be wrong.'

"But that can't be right, can it?"

* **Feature** - E

- **Q5.3** - Has this component been settled on prior to any interaction with the TA?
(C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark "Yes" if the students settle on an idea or move and move on or are ready to move on with solution before the interaction with the TA begins.

(In this case, the resolution may be correct or incorrect. The students may or may not be in agreement about the resolution. And they may be uncertain about their resolution.)

Mark "No" if the students do not settle on an idea or move and move on with their solution.

Note: Settling on an idea or move does not necessarily mean there is consensus among the group members. It does mean that the one or more students agree to use the idea or move and continue solution construction.

* **Example(s)** -

(Yes)

Students confirm all agree on the idea, and move on.

(C, CWhy, PWhy) "I think it's because of this. So let's go with that."

(P) S1: "I think we use this formula for Fnet. So let's go with that."

S2 and S3: "okay"

(No)

”Let’s wait on this and ask the TA.”

”I’m not sure. Let’s come back to this later.”

* **Feature** - Rs

– **Q5.4** - Is the resolution correct or incorrect? (C, CWhy, P, PWhy)

* **Possible Answers** - Correct or Incorrect

* **Feature** - R(red/green)

– **Q5.5** - Since this component was resolved correctly, was a component of the Actual Issue also resolved for the issue creator? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

On rare occasions, a correct resolution of a component(s) of the SPerceived Issue is or leads to a resolution of a component(s) of the Actual Issue.

Mark “Yes” if there was a resolution of a component(s) of the Actual Issue that developed at least in part from this resolution.

Mark “No” if there was no resolution of any component of the Actual Issue that developed at least in part from this resolution.

* **Feature** - R of AI

• **Actual Issue During the Interaction** - The Actual Issue is the root error or uncertainty that requires resolving.

– **Q7.2** - Is this component addressed during the interaction? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

In many cases, not all components of an issue are addressed during an interaction. This may happen due to certain components not being brought up at all, or being brought up but ignored.

Mark “Yes” if this component of the issue is directly focused on in any way during the interaction by the TA or students*.

Mark “No” if this component of the issue is never directly focused on in any way during the interaction by the TA or students.

Note: If the component is brought up, but nothing further is discussed about it, then it has not been addressed. (i.e. Simply bringing up this component within an interaction does not automatically mean it gets addressed.)

* **Feature** - Address

- **Q7.3** - Is this component addressed with the use of conceptual ideas? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Conceptual - a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement

Mark “Yes” if the TA and/or students pulls on conceptual ideas to address the issue.

Mark “No” if no conceptual ideas are mentioned or discussed in addressing the issue.

Note: If it is not clear whether an interaction is addressed with procedural moves or conceptual ideas, but it is clear that both are not necessarily used (as may be the case in a very brief interaction), default to “No” here.

· **Minor Rule Additions for 7.3(P)** -

(1) If the GTA asks a vague conceptual question as a way to correct something Procedural, code *not addressed with conceptual ideas*.

(2) If a conceptual idea is used to motivate a procedural move, code *is addressed with conceptual ideas*.

* **Example(s)** -

(Yes)

S or TA: “The rest masses change since you have one particle that splits into two.”

S or TA: “In this situation, we’re using the ball spring model to find the bond strength. The springs are the bonds.” _____

(No)

S or TA: “Set this to 0, because you don’t need it.”

S or TA: “What does mathematics tell us about multiplying variables by zero?”

S or TA: “You’re dividing by a vector here. How do we change that to a scalar?”

* **Feature** - Conc

– **Q7.4** - Is this component addressed with the use of procedure? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Procedure - a move or set of moves to be made during the construction of a solution or concerning the following of specific instructions

Mark “Yes” if the TA and/or students mentions or discusses procedure in ad-

dressing the issue.

Mark “No” if no procedure is mentioned or discussed in addressing the issue.

Note: If it is not clear whether an interaction is addressed with procedural moves or conceptual ideas, but it is clear that both are not necessarily used (as may be the case in a very brief interaction), default to “Yes” here.

Note: If it is not clear whether an interaction is addressed with procedural moves or conceptual ideas, but it is clear that only one of those is used (as may be the case in a very brief interaction), default to “Yes” here.

* **Example(s)** -

(Yes)

S or TA: “Use this for the magnitude of F_{net} , then find r_{hat} .”

S or TA: “Right here you have a U , but that will be 0.”

(No)

S or TA: “You start with one particle, then it splits, then they fly away from each other.”

* **Feature** - Proc

– **Q7.5** - Is this component resolved for the issue creator during the interaction? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if this component of the issue is no longer an issue, the resolution is correct, and there is no element of observable uncertainty remaining for the issue creator.

Mark “No” if this component of the issue remains unresolved, is resolved incorrectly, or is resolved correctly, but the issue creator still carries some uncertainty about the issue. Also mark “No” if this component goes away, but has not been observably resolved.

- **Minor Rule Additions** - Confirmation of an idea or answer alone is a valid Resolution so long as all demonstrated evidence of student understanding came before that confirmation.

- * **Feature** - R

- **Q7.6** - Even though the issue was not resolved for the issue creator, was the issue functionally resolved for the rest of the group? (C, CWhy, P, PWhy)

- * **Possible Answers** - Yes or No

- * **Instructions** -

Sometimes an issue will not be resolved for the issue creator, but may be resolved enough for the rest of the group, that those students continue on in constructing their solution.

Mark “Yes” if this component of the issue is no longer an issue for the rest of the group, the resolution is correct, and the rest of the group begins moving forward constructing their solution.

Mark “No” if this component of the issue remains unresolved for the rest of the group, is resolved incorrectly, or is resolved correctly, but the rest of the group is still uncertain about the resolution and does not move forward.

- * **Feature** - Rf

- **Q7.7** - Please select which characteristics are present after this component was addressed. Note: if no changes seem to have occurred, do not mark anything, and move

on to the next question. (C, CWhy, P, PWhy)

- * **Possible Answers** - multiple select: Error, Uncertainty

- * **Instructions** -

Even though a component of an issue remains unresolved for the issue creator, changes in how the issue is understood may occur over an interaction with the TA. For instance, if the students originally made an error, but showed no uncertainty, they may shift during the interaction to being uncertain about their prior decisions. Likewise, they initially may have been uncertain, but have since settled on an incorrect move or idea. In this question you'll mark which characteristics exist after this component of the issue is addressed, and later we'll compare this to your earlier responses to see if a shift has occurred.

Mark "Error" if the issue creator or group settles on a procedural move or a conceptual idea that is incorrect in some way.

Mark "Uncertainty" if the issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Note: These should be marked according to where the students are after this component of the issue has been addressed.

- * **Feature** - Shift

- **SPerceived Issue During the Interaction** - The SPerceived Issue is the issue students think they have.

- **Q8.2** - Do students now realize there is an issue?

- * **Possible Answers** - Yes or No

- * **Instructions** -

In most cases of students originally seeing “No Issue”, they will realize during the interaction that there really is an issue to address (even if they don't realize all components of the issue). However, sometimes the issue may be addressed or resolved in such a way that the students never realize there was an issue to begin with.

Mark “Yes” if the students realize an issue exists.

Mark “No” if the students continue to not see an issue, or an issue was not present to begin with.

* **Feature** - SPI

- **Q8.3** - Examine how each component (C, CWhy, P, PWhy) of the SPerceived Issue is addressed during the interaction.

* **Feature** - SPI

- **Address of the SPerceived Issue During the Interaction** - The SPerceived Issue is the issue students think they have.

- **Q9.2** - Is this component addressed during the interaction? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

In many cases, not all components of an issue are addressed during an interaction. This may happen due to certain components not being brought up at all, or being brought up but ignored.

Mark “Yes” if this component of the issue is directly focused on in any way during the interaction by the TA or students*.

Mark “No” if this component of the issue is never directly focused on in any way during the interaction by the TA or students.

Note: If the component is brought up, but nothing further is discussed about it, then it has not been addressed. (i.e. Simply bringing up this component within an interaction does not automatically mean it gets addressed.)

* **Feature** - Address

– **Q9.3** - Is this component addressed with the use of conceptual ideas? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Conceptual - a conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement

Mark “Yes” if the TA and/or students pulls on conceptual ideas to address the issue.

Mark “No” if no conceptual ideas are mentioned or discussed in addressing the issue.

Note: If it is not clear whether an interaction is addressed with procedural moves or conceptual ideas, but it is clear that both are not necessarily used (as may be the case in a very brief interaction), default to “No” here.

* **Example(s)** -

(Yes)

S or TA: “The rest masses change since you have one particle that splits into two.”

S or TA: “In this situation, we’re using the ball spring model to find the bond strength. The springs are the bonds.”

(No)

S or TA: “Set this to 0, because you don’t need it.”

S or TA: “What does mathematics tell us about multiplying variables by zero?”

S or TA: “You’re dividing by a vector here. How do we change that to a scalar?”

* **Feature** - Conc

– **Q9.4** - Is this component addressed with the use of procedure? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Procedure - a move or set of moves to be made during the construction of a solution or concerning the following of specific instructions

Mark “Yes” if the TA and/or students mentions or discusses procedure in addressing the issue.

Mark “No” if no procedure is mentioned or discussed in addressing the issue.

Note: If it is not clear whether an interaction is addressed with procedural moves or conceptual ideas, but it is clear that both are not necessarily used (as may be the case in a very brief interaction), default to “Yes” here.

* **Example(s)** -

(Yes)

S or TA: “Use this for the magnitude of F_{net} , then find r_{hat} .”

S or TA: “Right here you have a U, but that will be 0.”

(No)

S or TA: “You start with one particle, then it splits, then they fly away from each other.”

* **Feature** - Proc

– **Q9.5** - Is this component resolved during the interaction? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if this component of the issue is no longer an issue, the resolution is correct, and there is no element of observable uncertainty remaining for the issue creator.

Mark “No” if this component of the issue remains unresolved, is resolved incorrectly, or is resolved correctly, but the issue creator still carries some uncertainty about the issue. Also mark “No” if this component goes away, but has not been observably resolved.

* **Feature** - R

– **Q9.6** - Even though the issue was not resolved for the issue creator, was the issue functionally resolved for the rest of the group? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Sometimes an issue will not be resolved for the issue creator, but may be resolved enough for the rest of the group, that those students continue on in constructing their solution.

Mark “Yes” if this component of the issue is no longer an issue for the rest of the group, the resolution is correct, and the rest of the group begins moving forward constructing their solution.

Mark “No” if this component of the issue remains unresolved for the rest of the group, is resolved incorrectly, or is resolved correctly, but the rest of the group is still uncertain about the resolution and does not move forward.

* **Feature** - Rf

- **Q9.7** - Please select which characteristics are present after this component was addressed. (Note: if no changes seem to have occurred, do not mark anything, and move on to the next question.) (C, CWhy, P, PWhy)

* **Possible Answers** - multiple select: Error, Uncertainty

* **Instructions** -

Even though a component of an issue remains unresolved for the issue creator, changes in how the issue is understood may occur over an interaction with the TA. For instance, if the students originally made an error, but showed no uncertainty, they may shift during the interaction to being uncertain about their prior decisions. Likewise, they initially may have been uncertain, but have since settled on an incorrect move or idea. In this question you’ll mark which characteristics exist after this component of the issue is addressed, and later we’ll compare this to your earlier responses to see if a shift has occurred.

Mark “Error” if the issue creator or group settles on a procedural move or a conceptual idea that is incorrect in some way.

Mark “Uncertainty” if the issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Note: These should be marked according to where the students are after this component of the issue has been addressed.

* **Feature** - Shift

- **TAFocused Issue During the Interaction** - The TAFocused issue is the issue the TA focuses on during the interaction. This can typically be understood as an issue the TA diagnosis the students as having. However, sometimes the TA's diagnosis is not clearly expressed (for the researcher). In these cases, the TAFocused issue is the topic the TA chooses to use to address an issue. This can be the same as or different than the Actual Issue.

– **Q10.2** - Follow your table and mark which components of the TAFocused Issue are DIFFERENT from the Actual Issue. (Please select all that apply.)

* **Possible Answers** - multiple select: C, CWhy, P, PWhy

* **Instructions** -

Mark all components that differ in content from the Actual Issue. This includes boxes that are blank in the Actual Issue but contain content in the TAFocused Issue, and boxes that contain content in the Actual Issue, but are blank in the TAFocused Issue.

* **Feature** - TAFI Components

– **Q10.3** - Is PWhy the same as Conceptual (C) in this case?

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if the content of those boxes is identical.

Mark “No” if the content of those boxes is different.

* **Feature** - TAFI Components

- **Address of the TAFocused Issue During the Interaction** - The TAFocused issue is the issue the TA focuses on during the interaction.

- **Q10.4** - Follow your table and mark which components (if any) of the TAFocused Issue are empty. (Please select all that apply.) Note: Only components you marked earlier will show up as possible responses below.(C, CWhy, P, PWhy)

- * **Possible Answers** - multiple select: C, CWhy, P, PWhy

- * **Feature** - TAFI Components

- **Q11.1** - Now we will examine those components of the TAFocused Issue that are different from the Actual or SPerceived Issue but are not empty. The following questions concern those components of the TAFocused Issue as a whole.

- * **Feature** - TAFI

- **Q11.2** - How do students respond to the components of the TAFocused Issue that differ from the Actual or SPerceived Issue? (go along, get it, rectify, redirect)

- * **Possible Answers** - multiple select: go along, get it, rectify, redirect

- * **Instructions** -

- Mark “go along” if students attempt to follow the TA’s focus.

- Mark “get it” if students do more than just attempt to follow along at any time. Evidence includes students actively engaging with the TA’s focus verbally and through changes in their tone of voice (i.e. realization or confidence in voice, head nods, knowing looks, etc.).

- Mark “rectify” if students try to rectify the TAFocused Issue with either the Actual Issue or the SPerceived Issue at any point in the conversation. This is evidenced by verbal mentions of the Actual or SPerceived Issue and an attempt by the students (silently or out loud) to apply information from the TA’s focus to the Actual or SPerceived Issue.

Mark “redirect” if students make an attempt to redirect the TA’s attention to focusing on either the AI or the SPI at any point during the conversation.

· **Minor Rule Additions for 11.2_2(Get It)** - *Fully redefine this code.*

· **Minor Rule Additions for 11.2_4(Redirect)** - If a student directs the TA’s attention deeper into a topic rather than away from a topic, then it should *not* be marked as *Redirect* (e.g., a student directs the TA’s attention away from the procedure to be done and toward the reasoning behind it).

* **Example(s)** -

(go along)

Students listen to the TA, answer questions that are asked, and don’t leave the topic during this period

(get it)

Students nod or “yeah” in recognition of the topic being discussed, and answer questions more confidently

(don’t get it, but still go along)

Students are typically quieter, may “okay” frequently at the TA, answer questions (sometimes hesitantly) as asked, and stay on topic during this period

(rectify)

Students ask questions or make statements whose topics match the Actual or SPerceived Issue

Students make a move on their solution that takes information from the TAFocused Issue and applies it to the Actual or SPerceived Issue

(redirect)

S1 to TA: “Okay, but we want to know if if THIS one is 0, not that one.”

* **Feature** - Go, Get, Rectify, Redirect

– **Q11.3** - Is the TAFocused Issue resolved during the interaction?

* **Possible Answers** - Yes or No

* **Instructions** -

The TA typically will not leave unless he/she perceives his/her own issue to be resolved. Thus, we can not use the TA's expressions to help us determine if the TAFocused issue has been resolved.

Mark "Yes" only if the students demonstrate understanding of the correct resolution, and there is no element of observable uncertainty remaining for the creator of the Actual Issue. (Note: If students demonstrate understanding through correctly answering targeted questions by the TA, the expressions observed should include both correct answers along with changes in voice that signify a shift in answering from following along to realization.)

Mark "No" if the students do not demonstrate understanding of an correct solution, show no realization in their voices when responding to TA questions, or if the Actual Issue creator is still uncertain about the issue. Also mark "No" if this component goes away, but has not been observably resolved.

Note: Students may demonstrate this understanding during or after the interaction, so look through the remaining transcript before making a selection. Phrases like "oh, I see" or "I get you" alone do not count as demonstrations of understanding.

* **Feature** - R

- **How the Interaction Begins**

- **Q12.1** - Now that you've examined all the issues, examine how the interaction, as a whole, begins. Does the interaction begin on the Actual Issue, SPercieved Issue, TAFocused Issue, or something else?

- * **Possible Answers** - Actual, SPercieved, TAFocused, or Other

- * **Instructions** -

Typically, an interaction between students and their TA will begin with either the students or the TA asking a question about an issue, explaining something about an issue, or making an observation concerning a particular issue. In some cases, the interaction begins on something else: a different issue, a general check of the students work, etc.

Mark the appropriate issue that the interaction begins with. If the interaction does not begin on any particular issue, check "Other". (e.g. TA compliments students progress before bringing up any issues.) If the interaction begins on an issue with the same description as another issue, default to the highest listed issues in the issue table (Actual Issue, then SPercieved Issue, then TAFocused Issue)

- **Minor Rule Additions** - If the interaction begins on whether or no a number is correct, code *other*. If it begins on whether or not an idea is correct, code into the appropriate Issue of that idea.

- * **Feature** - I-Start

- **Other Actions During the Interaction**

- **Q13.1** - The following questions concern other actions students may take during an interaction. Typically, but not always, these actions would occur after the issue is addressed.

- **Q13.2** - Do the students restart all or a large part of the problem?

* **Possible Answers** - Yes or No

* **Instructions** -

In some cases, students may have to start over on their problem or erase a large part of it and redo that part. In these cases, students are not technically moving forward with their solution, but going back to redo a portion.

Mark “Yes” if students restart all or a large part of their solution. Signs of this include erasing multiple lines of a solution, all of their solution so far, or verbally mentioning having to redo part of their solution.

Mark “No” if students do not go back and restart all or a large part of their solution.

(Note: Going back to redo a small part of a calculation or fix a formula within their solution should also get marked as “No” since students are not really reconstructing their solution when they do that.)

* **Example(s)** -

Students erase all but the principle of their solution.

S1: “I guess we did that all wrong. Let’s start again doing it this way instead.”

* **Feature** - Restart

– **Q13.3** - Does the Actual Issue creator move forward with the solution construction?

* **Possible Answers** - Yes or No

* **Instructions** -

Students typically will not move forward in their solution construction until an interaction is over. However, sometimes they will shift their attention away from the TA or group discussion and begin moving forward with their solution construction before the interaction ends.

Mark “Yes” if the Actual Issue creator shifts his/her attention away from the TA or group discussion and moves on in constructing the solution.

Mark “No” if the Actual Issue creator has not moved on in constructing the solution before the interaction ends.

· **Minor Rule Additions** -

(1) If students’ behavior indicates they are moving forward right as the interaction is ending, code as *not moving forward* during the interaction.

(2) If students disengage from the interaction for a short period of time and then reengage, code as *not moving forward*.

* **Example(s)** -

S1 to TA: “Okay” (turns away from TA, but TA keeps talking)

S1 to S2: “We can use this.” (TA continues talking as if in the background)

S2 to S1: “so that would be .5 times 9.81...” (TA continues talking as if in the background)

* **Feature** - Move

- **Q13.4** - After restarting or moving forward, Do the students use information from the interaction or demonstrate some (correct or incorrect) understanding of the information?

* **Possible Answers** - Yes or No

* **Instructions** -

To understand how students are using whatever it is they got out of the interaction, we first need to see if they are expressing information from the interaction. These expressions may demonstrate understanding or a lack of understanding of something discussed within the interaction.

Mark “Yes” if students express, explicitly, information from the interaction. For example, the TA may have reviewed a part of a procedure to find a particular quantity. A student may then say, “So we should do the same thing down here for this quantity too, because....” This student is demonstrating an understanding of how to use the information they acquired in the interaction in a different setting.

Mark “No” if students do not express, explicitly, information from the interaction. In the example above, if instead the student was to respond, “We can do that,” the student is not making any expression explicit enough that we can say they understand the prior information.

Note: 1) Students moving forward in a solution does not count as evidence that they are expressing understanding or using information from the interaction. The information must be explicitly expressed. 2) Students following instructions; repeating a procedure in an identical situation or without additional reasoning; or repeating an idea verbatim are also not expressing an understanding as they are not bringing their own thoughts into the picture. 3) Students repeating a procedure in a novel (or slightly novel) situation does count as demonstrating understanding.

* **Feature** - Demo

– **Q13.5** - Do the students express positive or negative feelings?

* **Possible Answers** - Positive Feelings, Negative Feelings, or No Feelings expressed

* **Instructions** -

Students may express feelings about the interaction, how difficult the material is, or whether or not the interaction was helpful to them.

Mark “Positive Feelings” if these expressions are of a positive nature. Words often used for positive include helpful, clearer, better, etc. and are usually directed at the TA.

Mark “Negative Feelings” if these expressions are of a negative nature. Words often used for negative include, not helpful, difficult, confusing, etc. These are also directed at the TA, but often with a more positive bent to them (for cultural politeness).

Mark “No Feelings expressed” if the students make no comment about how they feel towards the problem or issue and no comment on how helpful or unhelpful the interaction was.

* **Example(s)** -

(Positive Feelings)

S: “Oh! That was really helpful.”

S: “That makes me feel good.”

(Negative Feelings)

S: “I’m never gonna get this.”

S: “I don’t like this lab.”

* **Feature** - Feel

- **Actual Issue Post-Interaction** - The Actual Issue is the root error or uncertainty that requires resolving.

- **Q14.1** - The following questions concern the Actual Issue after the interaction has ended. Note: If there is no transcription after the interaction, you may skip this and all remaining sections.

* **Feature - AI**

• **Actual Resolution or Shift Post-Interaction**

– **Q15.1** - Examine this component of the Actual Issue. Was this component resolved for the issue creator? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark “Yes” if this component of the issue is no longer an issue, the resolution is correct, and there is no element of observable uncertainty remaining for the issue creator.

Mark “No” if this component of the issue remains unresolved, is resolved incorrectly, or is resolved correctly, but the issue creator still carries some uncertainty about the issue. Also mark “No” if this component goes away, but has not been observably resolved.

* **Feature - R**

– **Q15.2** - Even though the issue was not resolved for the issue creator, was the issue functionally resolved for the rest of the group? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Sometimes an issue will not be resolved for the issue creator, but may be resolved enough for the rest of the group, that those students continue on in constructing their solution.

Mark “Yes” if this component of the issue is no longer an issue for the rest of the group, the resolution is correct, and the rest of the group begins moving forward constructing their solution.

Mark “No” if this component of the issue remains unresolved for the rest of the group, is resolved incorrectly, or is resolved correctly, but the rest of the group is still uncertain about the resolution and does not move forward.

* **Feature** - Rf

- **Q15.3** - Please select which characteristics of this component of the issue are present after the interaction has ended. (Note: if no changes seem to have occurred, do not mark anything, and move on to the next question.) (C, CWhy, P, PWhy)

* **Possible Answers** - multiple select: Error, Uncertainty

* **Instructions** -

Even though a component of an issue remains unresolved for the issue creator, changes in how the issue is understood may occur after an interaction with the TA. For instance, if the students originally made an error, but showed no uncertainty, they may shift after the interaction to being uncertain about their prior decisions. Likewise, they initially may have been uncertain, but have since settled on an incorrect move or idea. In this question you’ll mark which characteristics exist after an interaction has ended, and later we’ll compare this to your earlier responses to see if a shift has occurred.

Mark “Error” if the issue creator or group settles on a procedural move or a conceptual idea that is incorrect in some way.

Mark “Uncertainty” if the issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Note: These should be marked according to where the students are after the interaction has ended.

* **Feature** - Shift

- **SPerceived Issue Post-Interaction** - The SPerceived Issue is the issue students think they have.

- **Q16.1** - The following questions concern the SPerceived Issue after the interaction has ended. (Note: If the Actual Issue is the same as the SPerceived Issue and the students' treatment of the two issues is the same, you may skip through this section without answering the questions.)

* **Feature** - SPI

- **Q17.1** - Has this component been resolved? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

Mark "Yes" if the students settle on a resolution and move on or are ready to move on with solution (by the end of the transcript).

(In this case, the resolution may be correct or incorrect. The students may or may not be in agreement about the resolution. And they may be uncertain about their resolution.)

Mark "No" if the students do not settle on a resolution and move on with their solution by the end of the transcript. Also mark "No" if this component goes away, but has not been observably resolved.

* **Example(s)** -

(Yes)

Students confirm all agree on the idea, and move on.

(C, CWhy, PWhy) "I think it's because of this. So let's go with that."

(P) S1: "I think we use this formula for Fnet. So let's go with that."

S2 and S3: "okay"

(No)

”Let’s wait on this and ask the TA.”

”I’m not sure. Let’s come back to this later.”

* **Feature** - Rs

– **Q17.2** - Is the resolution correct or incorrect? (C, CWhy, P, PWhy)

* **Possible Answers** - Correct or Incorrect

* **Feature** - R(red/green)

– **Q17.3** - Since this component was resolved correctly, was a component of the Actual Issue also resolved? (C, CWhy, P, PWhy)

* **Possible Answers** - Yes or No

* **Instructions** -

On rare occasions, a correct resolution of a component(s) of the SPerceived Issue is or leads to a resolution of a component(s) of the Actual Issue.

Mark “Yes” if there was a resolution of a component(s) of the Actual Issue that developed at least in part from this resolution.

Mark “No” if there was no resolution of any component of the Actual Issue that developed at least in part from this resolution.

* **Feature** - R of AI

– **Q17.4** - Please select which characteristics of this component of the issue are present after the interaction has ended. (Note:if no changes seem to have occurred, do not mark anything, and move on to the next question.) (C, CWhy, P, PWhy)

* **Possible Answers** - multiple select: Error, Uncertainty

* **Instructions** -

Even though a component of an issue remains unresolved, changes in how the issue is understood may occur after an interaction with the TA. For instance, if the students originally made an error, but showed no uncertainty, they may shift after the interaction to being uncertain about their prior decisions. Likewise, they initially may have been uncertain, but have since settled on an incorrect move or idea. In this question you'll mark which characteristics exist after an interaction has ended, and later we'll compare this to your earlier responses to see if a shift has occurred.

Mark "Error" if the issue creator or group settles on a procedural move or a conceptual idea that is incorrect in some way.

Mark "Uncertainty" if the issue creator hesitates, questions, or otherwise expresses being uncertain about this component.

Note: These should be marked according to where the students are after the interaction has ended.

* **Feature** - Shift

- **Other Actions Post-Interaction** - The following questions concern other actions students may take after an interaction.

- **Q18.2** - Do the students restart all or a large part of the problem, or do they move forward with their solution construction, or neither?

- * **Possible Answers** - Restart, Move, or Neither

- * **Instructions** -

In some cases, students may have to start over on their problem or erase a large part of it and redo that part. In these cases, students are not technically moving

forward with their solution, but going back to redo a portion.

Mark “Restart” if students restart all or a large part of their solution. We are looking here for signs that most of or their whole approach to solving the problem was inappropriate. Signs of this include erasing multiple lines of a solution, all of their solution so far, or verbally mentioning having to redo multiple pieces of their solution.

(Note: Students may have to redo something to fix their issue. This should get “Move” unless the redo is a large portion of their solution or a complete change of approach.)

Mark “Move” if students move forward in constructing their solution, even if it includes redoing a piece of their solution (by the end of the transcript).

Mark “Neither” if students remain in the same place with their solution, stuck on something relevant to the issue (by the end of the transcript), or the transcript ends with no post-interaction dialogue present.

· **Minor Rule Additions** - If students Restart during the interaction, and continue that restarting process after the interaction, code as *Move forward* after the interaction.

* **Example(s)** -

(Restart)

Students erase all but the principle of their solution

S1: “I guess we did that all wrong. Let’s start again doing it this way instead.”

(Neither)

S1: “That didn’t help us with this. I guess we’re still stuck.”

* **Feature** - Move, Restart, Neither

- **Q18.3** - Do the students use information from the interaction or demonstrate some (correct or incorrect) understanding of the information?

* **Possible Answers** - Yes or No

* **Instructions** -

To understand how students are using whatever it is they got out of the interaction, we first need to see if they are expressing information from the interaction. These expressions may demonstrate understanding or a lack of understanding of something discussed within the interaction.

Mark “Yes” if students express, explicitly, information from the interaction. For example, the TA may have reviewed a part of a procedure to find a particular quantity. A student may then say, “So we should do the same thing down here for this quantity too, because....” This student is demonstrating an understanding of how to use the information they acquired in the interaction in a different setting.

Mark “No” if students do not express, explicitly, information from the interaction. In the example above, if instead the student was to respond, “Let’s try what we did before,” the student is not making any expression explicit enough that we can say they understand the prior information.

Note: 1) Students moving forward in a solution does not count as evidence that they are expressing understanding or using information from the interaction. The information must be explicitly expressed. 2) Students following instructions; repeating a procedure in an identical situation or without additional reasoning; or repeating an idea verbatim are also not expressing an understanding as they are not bringing their own thoughts into the picture. 3) Students repeating a

procedure in a novel (or slightly novel) situation does count as demonstrating understanding.

· **Minor Rule Additions -**

(1) In cases where the content to demonstrate is trivial, code as *not Demonstrating*.

(2) *Future iterations of this question should break it into the following components: (1) whether information talked about after the interaction actually related to the interaction, (2) whether students were just influenced by the interaction or explicitly showing understanding in some way, (3) whether there was anything that could be demonstrated due to the nature of the content in the Issue and the interaction, and (4) whether the information demonstrates correct or incorrect understanding.*

* **Example(s) -**

During the interaction, S1: “Ooooh. So rest energy does change.” TA: “Yeah, it does.”

After the interaction, S1: “I think we need to include rest energy in our equation now that we know it changes.”

* **Feature - Demo**

– **Q18.4 - Do the students continue a discussion started during the interaction?**

* **Possible Answers - Yes or No**

* **Instructions -**

Sometimes an interaction will begin a discussion that the students carry on after the TA has left.

Mark “Yes” if the students carry on discussing a topic begun during the interaction. We are looking for cognitive engagement with a topic.

Mark “No” if no continuation of a discussion occurs after the interaction has ended or if a new discussion begins after the interaction has ended. Note that the students simply moving forward with solution construction with no discussion or verbal cognitive engagement from the interaction should also get a “No”. Finally, mark “No” if students do not continue the discussion right after the interaction, even if they reference the interaction in a later discussion (note timestamps for this).

· **Minor Rule Additions** - *If the interaction ends and students talk afterward about an idea put forth during the interaction that is more than just information to use to move forward in their solution, they are continuing a discussion. Or, if it ends with the students having an idea of what they have to figure out, but having not yet fully figured it out, and the students talk about it after the interaction to figure it out, then they are continuing a discussion. If they are just moving forward without discussion, or using information to move forward but there is nothing really being “figured out”, then they are not continuing a discussion.*

* **Example(s)** -

(Yes)

During the interaction, TA writes out that correction piece on a formula students need. Students and TA discuss how that will be found.

After the interaction, students continue working on finding that.

(No)

During the interaction, S1: “Ooooh. So rest energy does change.” TA: “Yeah, it does.”

After the interaction, S1: “I think we need to include rest energy in our equation now that we know it changes.”

* **Feature** - Disc

– **Q18.5** - Do the students express positive or negative feelings?

* **Possible Answers** - Positive Feelings, Negative Feelings, No Feelings expressed

* **Instructions** -

Students may express feelings about the interaction, how difficult the material is, or whether or not the interaction was helpful to them.

Mark “Positive Feelings” if these expressions are of a positive nature. Words often used for positive include helpful, clearer, better, etc.

Mark “Negative Feelings” if these expressions are of a negative nature. Words often used for negative include, not helpful, difficult, confusing, etc.

Mark “No Feelings expressed” if the students make no comment about how they feel towards the problem or issue and no comment on how helpful or unhelpful the interaction was.

· **Minor Rule Additions** - If students express feelings that are not directed at anything in particular (e.g., “I’m so confused”) but were the first expression after the interaction, code as *Positive or Negative Feelings* as appropriate.

* **Example(s)** -

(Positive Feelings)

S: “That was really helpful.”

S: “That makes me feel good.”

(Negative Feelings)

S: “I’m never gonna get this.”

S: "I don't like this lab."

S: "I'm still really confused."

* **Feature** - Feel

B.5.4 Feature Descriptions

Table B.1: All Issues Framework Features and Descriptions

Framework Feature Descriptions

Title	Diagram Code	Feature	Description	Temporal Location based on GTA-student interaction
Issue Types	AI	Actual Issue	The root error or uncertainty that requires resolving as seen by the researcher/physics expert	multiple
	SPI	Student Perceived Issue	The issue students think they have	multiple
	TAFI	TA Focused Issue	The issue the TA addresses during the interaction	during
Issue Components	C	Conceptual	A conceptual idea of either physics or the physical situation or concerning the interpretation of a problem statement	multiple
	CWhy	Conceptual Why	Reasoning behind the conceptual idea	multiple
	P	Procedural	A move to be made during the construction or execution of a solution or concerning the following of specific instructions	multiple

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
	PWhy	Procedural Why	Reasoning behind the procedural move	multiple
	U	Uncertainty	The issue creator hesitates, questions, or otherwise expresses being uncertain about the issue component (C, CWhy, P, or PWhy)	before
Error/ Uncertainty	E	Error	A procedural move or a conceptual idea that is incorrect in some way concerning the issue component (C, CWhy, P, or PWhy) (differs under the Sperceived Issue in that students must express thinking that they are incorrect about the SPI component)	before
	Au	Automatically	The students do not notice that theyve created the Actual Issue (e.g. - simply writing down a formula or expressing an idea and moving on.), vs. thoughtfully when the issue is discussed in any way among students, or if the issue creator gave any indication of questioning or thinking through something (verbally or quietly) in creating the issue. (However, simply writing down a formula and moving on does not qualify as thoughtful creation.)	before
	Q-n,a	Question Generated	The issue creator began the Actual Issue by asking a question (either rhetorical or to the group)	before
Actual Issue Creation	In	Independently	The Actual Issue and supporting information was created solely by the student without any input or influence from other students	before
	Co	Collaborate	Other students added in specific information to help construct the same move or idea of the Actual Issue the issue creator is constructing (not oppose it)	before

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
	Ch	Challenge	Challenges to the Actual Issue are typically delivered more aggressively than inquiries or cooperative discussions. They can be in the form of statements or questions, and often are directed at the correctness of particular thoughts or ideas	before
	Qi	Inquiry Question	A non-challenging/inquiring question regarding the issue (even if only for a repeat of information). The question may be to learn more about the issue creators thoughts or to ask for repetition or clarification of a thought.	before
	Address	Address	The component (C, CWhy, P, PWhy) of the issue is directly focused on (in any way) during the interaction by the TA or students	during
Issue Address	Conc	Conceptual	The TA and/or students pulls on conceptual ideas (of either physics or the physical situation or concerning the interpretation of a problem statement) to address the issue component (C, CWhy, P, or PWhy)	during
	Proc	Procedural	The TA and/or students mentions or discusses procedure (a move or set of moves to be made during the construction of a solution or concerning the following of specific instructions) in addressing the issue component (C, CWhy, P, or PWhy)	during
	R	Resolution	The issue component (C, CWhy, P, or PWhy) is no longer an issue, the resolution is correct, and there is no element of observable uncertainty remaining for the issue creator (can occur before, during, and/or after an interaction with the GTA)	multiple

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
Issue Closure	Rf	Functional Resolution	An issue component (C, CWhy, P, or PWhy) that is not resolved for the issue creator but is resolved enough for the rest of the group (and the resolution is correct), that those students continue on in constructing their solution (can occur during, and/or after an interaction with the GTA)	multiple
	Shift	Shift	Even if the component of an issue (C, CWhy, P, or PWhy) remains unresolved for the issue creator, changes in how the issue is understood may occur over an interaction with the TA: it may Shift from Error to Uncertainty or vice versa (can occur during, and/or after an interaction with the GTA)	multiple
	Rs	Settled Resolution	Applies to the SPerceived Issue before and/or after the GTA-student interaction only: the students settle on an idea or move and move on with solution. (In this case, the resolution may be correct or incorrect. The students may or may not be in agreement about the resolution. And they may be uncertain about their resolution.)	multiple
iStart	TAiStart	TA begins interaction	TA begins interaction	during
	SiStart	Student begins interaction	Student begins interaction	during
iTopic	TAiTopic	TA begins focal topic	TA begins focal topic	during
	SiTopic	Student begins focal topic	Student begins focal topic	during

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
Istart	AI	Actual Issue	The interaction begins on the Actual Issue	during
	SPI	Student Perceived Issue	The interaction begins on the Student Perceived Issue	during
	TAFI	TA Focused Issue	The interaction begins on the TA Focused Issue	during
	Other	Other	The interaction does not begin on any particular issue (e.g. TA compliments students progress before bringing up any issues or studnets check their answer)	during
Diagnosis	Abbrev	Abbreviated	Usually brief questions and answers between the students and GTA, there has not been sufficient time to really assess what might need attending, and there has been no extra effort made by the TA to get more information on what might need attending	during
	Work	Students' Work	The TA looks over students whiteboard work, calculator work, or PC work/answers to figure out what the students have done/thought	during
	Listen	Listen	The TA listens to students talk amongst themselves or talk to the TA to figure out what the students have done/thought. At least one complete idea on an issue is shared by the students	during
	Active	Active	The TA guides the students to verbalize their situation, asking probing questions as needed, and/or students work along with the GTA to review their work to find errors	during

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
Directs	Tadirect	TA directs interaction	The TA controls the topic and flow of conversation. Students may participate in the conversation - may answer questions and/or share their ideas - but the TA is guiding the the course of the dialogue	during
	Sdirect	Student directs interaction	The students will generally control the flow and direction of conversation either through their statements or their questions	during
How Di-rects: TA	Sinput	Encouragement of Student Input	The TA guides or directs students to give input through his/her actions towards the student, usually in the form of questions, directions, or purposeful pauses	during
	Question	Question	The students have asked one or more questions of the TA, but do not include any of their own ideas within those questions, and the GTA answers them directly	during
How Di-rects: Student	Share	Share	The students talk about what they think and share their own ideas and processes. This is what guides the flow of the conversation.	during
	Disengage	Disengage	The students will largely ignore the TA and do their own thing. The TA may continue talking here, but the students are not really following the TA.	during
Sshare	Prompt	Prompt	Probing questions by the TA (How?, Why?) to get at how or why students thought or did something with their solution construction. Or, purposeful silence left by the TA as space for students to share.	during

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
	Own	Own	There is no purposeful, explicit prompting or silent space by the TA, but students are sharing their ideas anyway. The TA may allow space for that sharing, but does not necessarily create the space before sharing begins.	during
	Get	Get	Students do more than just attempt to follow along at any time. Evidence includes students actively engaging with the TAs focus verbally and through changes in their tone of voice (i.e. realization or confidence in voice, head nods, knowing looks, etc.).	during
Student Re-sponses to TAFI	Rectify	Rectify	Students try to rectify the TAFocused Issue with either the Actual Issue or the SPerceived Issue at any point in the conversation. This is evidenced by verbal mentions of the Actual or SPerceived Issue and an attempt by the students (silently or out loud) to apply information from the TAs focus to the Actual or SPerceived Issue.	during
	Redirect	Redirect	Students make an attempt to redirect the TAs attention to focusing on either the Actual Issue or the Sperceived Issue at any point during the conversation.	during
	R	Resolution	The students demonstrate understanding of the correct resolution, and there is no element of observable uncertainty remaining for the creator of the Actual Issue. (this is not component specific but applies to the entire TAFI)	during

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Table B.1 – *Continued from previous page*

Title	Diagram Code	Feature	Description	Temporal Location
	Restart	Restart	Students restart all or a large part of their solution. Signs of this include erasing multiple lines of a solution, all of their solution so far, or verbally mentioning having to redo part of their solution. (can occur during, and/or after an interaction with the GTA)	multiple
	Move	Move	The Actual Issue creator shifts his/her attention away from the TA or group discussion and moves on in constructing the solution (can occur during, and/or after an interaction with the GTA)	multiple
Other Student Actions	Demo	Demonstrate	Students express, explicitly, information from the interaction that shows an understanding of how to use the information they acquired in the interaction in a different setting. (can occur during, and/or after an interaction with the GTA)	multiple
	Feel	Feel	Students express feelings about the interaction, how difficult the material is, or whether or not the interaction was helpful to them (positively or negatively). (can occur during, and/or after an interaction with the GTA)	multiple
	Discuss	Discuss	The students carry on discussing a topic begun during the interaction. This involves cognitive engagement with a topic, rather than simply following a directed procedure	multiple

Appendix C

Agreement Results

Table C.1: Reliability results for all survey questions. Survey questions identify the presence of various features of the framework. The “*” denotes α_K values that may be lower than expected due to prevalence.

Issue Feature Reliability Results

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Q2.5	42	0.60	0.81	51.57	31.47	29.89	18.24
Q2.6	17	0.53	0.76	51.47	31.41	29.83	18.20
Q2.8	8	0.50	0.75	51.62	31.50	29.92	18.26
Q2.9	22	0.65	0.95	117.76	71.86	68.93	42.06
Q2.10	22	0.17	0.77	62.45	38.11	36.31	22.15

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Q2.11	42	0.66*	0.90	64.60	39.42	37.58	22.93
Q2.12	40	0.75	0.88	51.43	31.38	29.81	18.19
Q3.1(C)	12	0.20	0.58	51.58	31.47	29.90	18.24
Q3.1(CWhy)	6	-	1.00	-	-	-	-
Q3.1(P)	37	0.46	0.73	51.42	31.37	29.80	18.18
Q3.1(PWhy)	3	-0.25	0.33	58.11	35.46	33.75	20.59
Q3.2(C)	12	0.57	0.83	54.99	33.55	31.91	19.47
Q3.2(CWhy)	6	1.00	1.00	51.41	31.37	29.80	18.18
Q3.2(P)	37	0.51*	0.81	54.10	33.01	31.38	19.15
Q3.2(PWhy)	3	0.00	0.67	58.11	35.46	33.75	20.59
Q3.3(C)	12	-	1.00	-	-	-	-
Q3.3(CWhy)	6	-	1.00	-	-	-	-
Q3.3(P)	37	0.00	0.97	507.21	309.50	298.65	182.24
Q3.3(PWhy)	3	-	1.00	-	-	-	-
Q5.1(C)	7	-	1.00	-	-	-	-
Q5.1(CWhy)	2	0.00	0.50	51.41	31.37	29.80	18.18
Q5.1(P)	29	0.45*	0.83	60.16	36.71	34.96	21.33
Q5.1(PWhy)	5	1.00	1.00	59.39	36.24	34.50	21.05
Q5.2(C)	7	-0.08	0.71	63.47	38.73	36.91	22.52

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Table C.1 – Continued from previous page

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Q5.2(CWhy)	2	-	1.00	-	-	-	-
Q5.2(P)	29	0.07*	0.66	54.94	33.53	31.88	19.45
Q5.2(PWhy)	5	-0.13	0.60	53.65	32.74	31.12	18.99
Q5.3(C)	7	-0.18	0.57	56.95	34.75	33.07	20.18
Q5.3(CWhy)	2	-0.5	0.00	-	-	-	-
Q5.3(P)	29	0.35*	0.83	64.71	39.49	37.64	22.97
Q5.3(PWhy)	5	-	1.00	-	-	-	-
Q5.4(C)	0	-	-	-	-	-	-
Q5.4(CWhy)	0	-	-	-	-	-	-
Q5.4(P)	2	0.00	0.50	51.41	31.37	29.80	18.18
Q5.4(PWhy)	0	-	-	-	-	-	-
Q5.5(C)	0	-	-	-	-	-	-
Q5.5(CWhy)	0	-	-	-	-	-	-
Q5.5(P)	1	0	1.00	-	-	-	-
Q5.5(PWhy)	0	-	-	-	-	-	-
Q7.2(C)	12	0.84	0.92	51.41	31.37	29.80	18.18
Q7.2(CWhy)	6	1.00	1.00	52.08	31.78	30.19	18.42
Q7.2(P)	37	0.28*	0.89	102.62	62.62	60.00	36.61
Q7.2(PWhy)	3	1.00	1.00	52.08	31.78	30.19	18.42

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Q7.3(C)	6	-0.22	0.50	54.20	33.07	31.44	19.19
Q7.3(CWhy)	4	1.00	1.00	54.99	33.55	31.91	19.47
Q7.3(P)	32	0.82	0.94	57.38	35.01	33.31	20.33
Q7.3(PWhy)	2	-	1.00	-	-	-	-
Q7.4(C)	6	0.69	0.83	51.41	31.37	29.80	18.18
Q7.4(CWhy)	4	0.53	0.75	51.41	31.37	29.80	18.18
Q7.4(P)	32	0.66	0.97	161.64	98.63	94.82	57.86
Q7.4(PWhy)	2	-	1.00	-	-	-	-
Q7.5(C)	6	0.59	0.83	54.20	33.07	31.44	19.19
Q7.5(CWhy)	4	-0.17	0.50	51.41	31.37	29.80	18.18
Q7.5(P)	31	0.46*	0.81	56.74	34.62	32.94	20.10
Q7.5(PWhy)	2	0.00	0.50	51.41	31.37	29.80	18.18
Q7.6(C)	1	-	1.00	-	-	-	-
Q7.6(CWhy)	0	-	-	-	-	-	-
Q7.6(P)	4	-	1.00	-	-	-	-
Q7.6(PWhy)	0	-	-	-	-	-	-
Q7.7_E(C)	1	-	1.00	-	-	-	-
Q7.7_U(C)	1	0	0.00	-	-	-	-
Q7.7_E(CWhy)	0	-	-	-	-	-	-

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Q7.7_U(CWhy)	0	-	-	-	-	-	-
Q7.7_E(P)	2	-	1.00	-	-	-	-
Q7.7_U(P)	2	-	1.00	-	-	-	-
Q7.7_E(PWhy)	0	-	-	-	-	-	-
Q7.7_U(PWhy)	0	-	-	-	-	-	-
Q8.2	15	0.71	0.87	52.08	31.78	30.19	18.42
Q9.2(C)	4	-	1.00	-	-	-	-
Q9.2(CWhy)	1	-	1.00	-	-	-	-
Q9.1(P)	16	0.55	0.81	53.37	32.56	30.95	18.89
Q9.2(PWhy)	4	1.00	1.00	54.99	33.55	31.91	19.47
Q9.3(C)	4	-	1.00	-	-	-	-
Q9.3(CWhy)	1	-	1.00	-	-	-	-
Q9.3(P)	10	-0.27	0.50	54.69	33.37	31.73	19.36
Q9.3(PWhy)	3	-	1.00	-	-	-	-
Q9.4(C)	4	0.00	0.75	69.27	42.27	40.33	24.61
Q9.4(CWhy)	1	0	0.00	-	-	-	-
Q9.4(P)	10	0.63	0.90	67.45	41.16	39.26	23.96
Q9.4(PWhy)	3	-	1.00	-	-	-	-
Q9.5(C)	2	1.00	1.00	51.41	31.37	29.80	18.18

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8$, CL = .95)	N ($\alpha_K = .8$, CL = .90)	N ($\alpha_K = .667$, CL = .95)	N ($\alpha_K = .667$, CL = .90)
Q9.5(CWhy)	1	-	1.00	-	-	-	-
Q9.5(P)	3	1.00	1.00	52.08	31.78	30.19	18.42
Q9.5(PWhy)	2	0.00	0.50	51.41	31.37	29.80	18.18
Q9.6(C)	1	-	1.00	-	-	-	-
Q9.6(CWhy)	0	-	-	-	-	-	-
Q9.6(P)	1	0	0.00	-	-	-	-
Q9.6(PWhy)	0	-	-	-	-	-	-
Q9.7_E(C)	1	-	1.00	-	-	-	-
Q9.7_U(C)	1	-	1.00	-	-	-	-
Q9.7_E(CWhy)	0	-	-	-	-	-	-
Q9.7_U(CWhy)	0	-	-	-	-	-	-
Q9.7_E(P)	1	-	1.00	-	-	-	-
Q9.7_U(P)	1	-	1.00	-	-	-	-
Q9.7_E(PWhy)	0	-	-	-	-	-	-
Q9.7_U(PWhy)	0	-	-	-	-	-	-
Q11.2_(go along)	28	-0.02	0.93	206.69	126.13	121.39	74.07
Q11.2_(get it)	28	-0.33	0.32	51.41	31.37	29.80	18.18
Q11.2_(rectify)	27	0.28*	0.78	61.41	37.47	35.69	21.78
Q11.2_(redirect)	27	0.14*	0.78	68.32	41.69	39.77	24.27

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Table C.1 – Continued from previous page

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Q11.3	28	0.52*	0.86	62.12	37.91	36.12	22.04
Q12.1	42	0.73	0.81	62.20	37.95	36.16	22.06
Q13.2	48	0.48	0.96	178.33	108.82	104.66	63.86
Q13.3	42	0.73*	0.93	67.13	40.96	39.07	23.84
Q13.4	7	0.00	0.43	52.53	32.05	30.46	18.59
Q13.5	48	-0.03	0.90	144.63	88.25	84.78	51.73
Q15.1(C)	5	0.25	0.60	52.20	31.85	30.26	18.47
Q15.1(CWhy)	2	-0.5	0.00	-	-	-	-
Q15.1(P)	7	1.00	1.00	51.44	31.39	29.81	18.19
Q15.1(PWhy)	0	-	-	-	-	-	-
Q15.2(C)	1	-	1.00	-	-	-	-
Q15.2(CWhy)	0	-	-	-	-	-	-
Q15.2(P)	4	0.00	0.75	69.27	42.27	40.33	24.61
Q15.2(PWhy)	0	-	-	-	-	-	-
Q15.3.E(C)	1	-	1.00	-	-	-	-
Q15.3.U(C)	1	-	1.00	-	-	-	-
Q15.3.E(CWhy)	0	-	-	-	-	-	-
Q15.3.U(CWhy)	0	-	-	-	-	-	-
Q15.3.E(P)	3	0.00	0.67	58.11	35.46	33.75	20.59

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Q15.3.U(P)	3	1.00	1.00	52.08	31.78	30.19	18.42
Q15.3.E(PWhy)	0	-	-	-	-	-	-
Q15.3.U(PWhy)	0	-	-	-	-	-	-
Q17.1(C)	1	-	1.00	-	-	-	-
Q17.1(CWhy)	0	-	-	-	-	-	-
Q17.1(P)	4	0.53	0.75	51.41	31.37	29.80	18.18
Q17.1(PWhy)	1	-	1.00	-	-	-	-
Q17.2(C)	0	-	-	-	-	-	-
Q17.2(CWhy)	0	-	-	-	-	-	-
Q17.2(P)	1	-	1.00	-	-	-	-
Q17.2(PWhy)	1	-	1.00	-	-	-	-
Q17.3(C)	0	-	-	-	-	-	-
Q17.3(CWhy)	0	-	-	-	-	-	-
Q17.3(P)	0	-	-	-	-	-	-
Q17.3(PWhy)	0	-	-	-	-	-	-
Q17.4.E(C)	0	-	-	-	-	-	-
Q17.4.U(C)	0	-	-	-	-	-	-
Q17.4.E(CWhy)	0	-	-	-	-	-	-
Q17.4.U(CWhy)	0	-	-	-	-	-	-

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Table C.1 – *Continued from previous page*

Question Number	Reliability Results			Sample Size N required for various combinations of α_K s and CL confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Q17.4.E(P)	0	-	-	-	-	-	-
Q17.4.U(P)	0	-	-	-	-	-	-
Q17.4.E(PWhy)	0	-	-	-	-	-	-
Q17.4.U(PWhy)	0	-	-	-	-	-	-
Q18.2	41	0.12*	0.80	107.28	65.46	62.75	38.29
Q18.3	42	0.25	0.62	51.41	31.37	29.80	18.18
Q18.4	42	-0.04	0.69	60.77	37.08	35.31	21.55
Q18.5	40	0.63	0.93	80.59	49.18	47.01	28.68

Table C.2: Issue Content Category Reliability Results. Bold under “Sample Size N” columns indicates necessary sample size was exceeded in this study. Bold under “Reliability Results” columns indicates $\alpha_K \geq 0.667$ or Simple Agreement ≥ 0.8 for adequate sample size.

Issue Content Category Reliability Results

Sorting Task	Reliability Results			Sample Size N required for various combinations of α_K s and confidence levels			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Con vs. Ex	44	0.64	0.84	52.25	31.88	30.29	18.48
GS vs. SA	30	0.89	0.97	61.62	37.60	35.82	21.86
UC vs. O	13	1.00	1.00	51.42	31.37	29.80	18.18

Table C.3: Characteristics of the Interaction Reliability Results. The “*” denotes α_K values that may be lower than expected due to prevalence. Bold under “Sample Size N” columns indicates necessary sample size was exceeded in this study. Bold under “Reliability Results” columns indicates $\alpha_K \geq 0.667$ or Simple Agreement ≥ 0.8 for adequate sample size.

Characteristics of the Interaction Reliability Results

Sorting Task	Reliability Results			Sample Size N required for various combinations of α_K s and Confidence Levels (CL)			
	Sample Size (N)	α_K	Simple Agreement	N ($\alpha_K = .8, CL = .95$)	N ($\alpha_K = .8, CL = .90$)	N ($\alpha_K = .667, CL = .95$)	N ($\alpha_K = .667, CL = .90$)
Diagnosis	53	0.55	0.68	65.21	39.79	37.93	23.15
Who Directed	52	0.73*	0.92	63.3	38.62	36.81	22.46
How Students Directed	9	0.52	0.67	58.11	35.46	33.75	20.59
How TA Directed	44	0.77	0.89	51.42	31.38	29.8	18.19
Do Students Share Ideas	54	0.68*	0.91	62.87	38.37	36.56	22.31
How Do Students Share Ideas	9	0.15	0.56	51.49	31.42	29.84	18.21

Appendix D

Framework Results

Table D.1: This table shows frequency results for all framework features by Issue Content Category. Bolded numbers indicate those features considered typical - occurring 65% of the time or more. “*” indicates daughter features that are present 65% of the times the parent features is present (only when the parent feature is bolded) and over 50% of the total times. “**” indicates features that are present at least 65% of the time when added together (e.g. SPI -P same + SPI - P diff). “+” appears once and indicates that 65% of unique diagnoses are Work, even though Work diagnoses account for only half of all Unit Conversion Issue diagnoses. In the section of the SPI During the interaction only rows for which the SPI component is different from the AI component are displayed (all gray). When the components are the same, those features only get counted in the AI rows to avoid double counting.

Framework Results Across Issue Content Categories

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
AI-C	AI-C present	1	7	-	-	-	8
	Uncertainty (U)	1	3	-	-	-	4
	Error (E)	-	7	-	-	-	7
	Resolution (R)	-	-	-	-	-	0

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
AI-C	Address	1	5	-	-	-	6
	w/ Conceptual (Conc)	1	4	-	-	-	5
	w/ Procedural (Proc)	1	3	-	-	-	4
	Resolution (R)	-	5	-	-	-	5
	Functional Resolution (Rf)	1	-	-	-	-	1
	Shift	-	-	-	-	-	0
AI-C	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	1	1	-	-	-	2
	Shift	-	-	-	-	-	0
AI-CWhy	AI-CWhy present	-	6	-	-	-	6
	Uncertainty (U)	-	-	-	-	-	0
	Error (E)	-	3	-	-	-	3
	Resolution (R)	-	-	-	-	-	0
AI-CWhy	Address	-	4	-	-	-	4
	w/ Conceptual (Conc)	-	3	-	-	-	3
	w/ Procedural (Proc)	-	1	-	-	-	1
	Resolution (R)	-	2	-	-	-	2
	Functional Resolution (Rf)	-	1	-	-	-	1
	Shift	-	-	-	-	-	0
AI-CWhy	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	-	1	-	-	-	1
	Shift	-	-	-	-	-	0
AI-P present		5	18	8	5	-	36

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AI-P

Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
AI-P	Uncertainty (U)	5*	12*	1	1	-	19
	Error (E)	-	12*	8*	5*	-	25*
	Resolution (R)	-	-	-	1	-	1
	Address	5*	15*	8*	4*	-	32*
	w/ Conceptual (Conc)	2	5	-	-	-	7
	w/ Procedural (Proc)	5*	14*	8*	4*	-	31*
	Resolution (R)	3	13*	4	3	-	23
	Functional Resolution (Rf)	-	1	2	-	-	3
	Shift	-	-	1	-	-	1
	Resolution (R)	-	-	2	1	-	3
AI-P	Functional Resolution (Rf)	-	2	-	-	-	2
	Shift	1	1	-	-	-	2
AI-PWhy	AI-PWhy present	-	2	1	-	-	3
	Uncertainty (U)	-	1	-	-	-	1
	Error (E)	-	-	-	-	-	0
	Resolution (R)	-	-	-	-	-	0
AI-PWhy	Address	-	1	1	-	-	2
	w/ Conceptual (Conc)	-	-	-	-	-	0
	w/ Procedural (Proc)	-	1	1	-	-	2
	Resolution (R)	-	-	1	-	-	1
	Functional Resolution (Rf)	-	1	-	-	-	1
	Shift	-	-	-	-	-	0
AI-PWhy	Resolution (R)	-	-	-	-	-	0

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
	Functional Resolution (Rf)	-	1	-	-	-	1
	Shift	-	-	-	-	-	0
AI-C/PWhy (COMBO)	AI-C/PWhy Combo present	-	4	-	-	-	4
	Uncertainty (U)	-	1	-	-	-	1
	Error (E)	-	2	-	-	-	2
	Resolution (R)	-	-	-	-	-	0
AI-C/PWhy (COMBO)	Address	-	-	-	-	-	0
	w/ Conceptual (Conc)	-	-	-	-	-	0
	w/ Procedural (Proc)	-	-	-	-	-	0
	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	-	-	-	-	-	0
	Shift	-	-	-	-	-	0
AI-C/PWhy (COMBO)	Resolution (R)	-	1	-	-	-	1
	Functional Resolution (Rf)	-	-	-	-	-	0
	Shift	-	-	-	-	-	0
AI Creation	Automatic (Au)	2	5	7	4	-	18
	Question Generated, Answered (Q-a)	1	6	1	1	-	9
	Question Generated, Un-answered (Q-na)	1	3	-	-	-	4
	Independent (In)	-	1	-	-	-	1
	Collaborative (Co)	4	13*	1	1	-	19
	Challenge (Ch)	-	5	-	1	-	6

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Table D.1 – *Continued from previous page*

Issue Content Categories			GS	SA	UC	Other	NI	Total
# of Issues			6	23	8	5	5	47
Inquiry Question (Qi)			3	15	3	1	-	22
SPI-C	SPI-C present and same as AI		1	3	-	-	-	4
	SPI-C present and different from AI		-	3	-	-	-	3
	Total SPI-C		1	6	-	-	-	7
Uncertainty (U)			1	3	-	-	-	4
Uncertainty (U) - different from AI			-	3	-	-	-	3
Error (E)			-	-	-	-	-	0
Error (E) - different from AI			-	-	-	-	-	0
SPI-C	Resolution (R) Correct		-	-	-	-	-	0
	Resolution (R) Correct - different from AI		-	-	-	-	-	0
	Resolution (R) Incorrect		-	1	-	-	-	1
	Resolution (R) Incorrect - different from AI		-	1	-	-	-	1
SPI-C	Address - different from AI		-	3	-	-	-	3
	w/ Conceptual (Conc) - different from AI		-	3	-	-	-	3
	w/ Procedural (Proc) - different from AI		-	-	-	-	-	0
	Resolution (R) - different from AI		-	1	-	-	-	1
	Resolution (R) Correct		-	-	-	-	-	0

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
SPI-C	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-CWhy	SPI-CWhy present and same as AI	-	2	-	-	-	2
	SPI-CWhy present and different from AI	-	-	-	-	-	0
	Total SPI-CWhy	-	2	-	-	-	2
SPI-CWhy	Uncertainty (U)	-	2	-	-	-	2
	Uncertainty (U) - different from AI	-	-	-	-	-	0
	Error (E)	-	-	-	-	-	0
	Error (E) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	2	-	-	-	2
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
	Address - different from AI	-	-	-	-	-	0
	w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0
w/ Procedural (Proc) - different from AI	-	-	-	-	-	0	

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SPI-
CWhyTable D.1 – *Continued from previous page*

Issue Content Categories	GS	SA	UC	Other	NI	Total
# of Issues	6	23	8	5	5	47
Resolution (R) - different from AI	-	-	-	-	-	0
Resolution (R) Correct	-	-	-	-	-	0
Resolution (R) Correct - different from AI	-	-	-	-	-	0
SPI-CWhy Resolution (R) Incorrect	-	-	-	-	-	0
Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-P present and same as AI	5	12	1	1	-	19
SPI-P present and different from AI	-	5	3	-	-	8
Total SPI-P	5	17	4	1	-	27
Uncertainty (U)	5	12**	1	-	-	18
Uncertainty (U) - different from AI	-	4**	1	-	-	5
Error (E)	1	2	1	1	-	5
Error (E) - different from AI	-	-	2	-	-	2
SPI-P Resolution (R) Correct	-	1	-	1	-	2
Resolution (R) Correct - different from AI	-	-	1	-	-	1
Resolution (R) Incorrect	-	3	-	-	-	3
Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
Address - different from AI	-	4	2	-	-	6

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
SPI-P	w/ Conceptual (Conc) - different from AI	-	1	-	-	-	1
	w/ Procedural (Proc) - different from AI	-	4	2	-	-	6
	Resolution (R) - different from AI	-	1	1	-	-	2
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
SPI-P	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-PWhy	SPI-PWhy present and same as AI	-	1	1	-	-	2
	SPI-PWhy present and different from AI	-	1	2	-	-	3
	Total SPI-PWhy	-	2	3	-	-	5
	Uncertainty (U)	-	1	-	-	-	1
	Uncertainty (U) - different from AI	-	-	-	-	-	0
	Error (E)	-	-	-	-	-	0
	Error (E) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
SPI-PWhy	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
	Address - different from AI	-	1	1	-	-	2
	w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0
	w/ Procedural (Proc) - different from AI	-	1	1	-	-	2
	Resolution (R) - different from AI	-	1	1	-	-	2
SPI-PWhy	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	1	-	-	1
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-C/PWhy (COMBO)	SPI-C/PWhy present and same as AI	-	-	-	-	-	0
	SPI-C/PWhy present and different from AI	-	-	-	-	-	0
	Total SPI-C/PWhy	-	-	-	-	-	0
	Uncertainty (U)	-	-	-	-	-	0
	Uncertainty (U) - different from AI	-	-	-	-	-	0
	Error (E)	-	-	-	-	-	0
	Error (E) - different from AI	-	-	-	-	-	0
Resolution (R) Correct	-	-	-	-	-	0	

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Table D.1 – *Continued from previous page*

	Issue Content Categories	GS	SA	UC	Other	NI	Total
SPI- C/PWhy (COMBO)	# of Issues	6	23	8	5	5	47
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
	Address - different from AI	-	-	-	-	-	0
SPI- C/PWhy (COMBO)	w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0
	w/ Procedural (Proc) - different from AI	-	-	-	-	-	0
	Resolution (R) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
	AI present - TAFI same	1	3	-	-	-	4
	AI present - TAFI mostly same	-	2	-	-	-	2
TAFI - C	AI present - TAFI different	-	3	-	-	-	3
	AI present - TAFI absent	-	1	-	-	-	1

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
	AI absent - TAFI present	1	1	-	-	-	2
	AI absent - TAFI absent	3	9	8	4	2	26
	Total TAFI-C present	2	9	-	-	-	11
	AI present - TAFI same	-	-	-	-	-	0
TAFI - CWhy	AI present - TAFI mostly same	-	-	-	-	-	0
	AI present - TAFI different	-	3	-	-	-	3
	AI present - TAFI absent	-	3	-	-	-	3
	AI absent - TAFI present	-	1	-	-	-	1
	AI absent - TAFI absent	6	16	8	5	5	40
	Total TAFI-CWhy present	-	4	-	-	-	4
	AI present - TAFI same	1	10	6	3	-	20
TAFI - P	AI present - TAFI mostly same	4	2	1	1	-	8
	AI present - TAFI different	-	4	1	-	-	5
	AI present - TAFI absent	-	2	-	1	-	3
	AI absent - TAFI present	1	-	-	-	5	6

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
AI absent - TAFI absent		-	5	-	-	-	5
Total TAFI-P present		6	16	8	4	5	39
TAFI PWhy	AI present - TAFI same	-	-	-	-	-	0
	AI present - TAFI mostly same	-	-	-	-	-	-
	AI present - TAFI different	-	-	-	-	-	0
	AI present - TAFI absent	-	4	1	-	-	5
	AI absent - TAFI present	1	1	1	-	-	3
	AI absent - TAFI absent	4	14	6	4	2	30
	Total TAFI-PWhy present	1	1	2	-	-	4
TAFI C/PWhy COMBO	AI present - TAFI same	-	1	-	-	-	1
	AI present - TAFI mostly same	-	-	-	-	-	0
	AI present - TAFI different	-	1	-	-	-	1
	AI present - TAFI absent	-	-	-	-	-	0
	AI absent - TAFI present	1	2	-	1	3	7
	AI absent - TAFI absent	-	-	-	-	-	0

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
Total TAFI-C/PWhy present		1	4	-	1	3	9
TAFI Student Response	Get	5	11	6	4	1	27
	Rectify	-	5	1	1	2	9
	Redirect	1	4	1	-	-	6
	Resolution (R)	4	20	6	5	4	39
	Not Resolved - Full Match w/ AI	-	-	2	-	-	2
	Not Resolved - Partial Match w/ AI	2	-	-	-	-	2
	Not Resolved - Full Mismatch w/ AI	-	2	-	-	1	3
	Not Resolved - Blank	-	1	-	-	-	1
Beginning Issue	AI	4	8	-	-	-	12
	SPI	-	6	-	-	-	6
	TAFI	2	2	-	1	1	6
	Other	-	7	8	4	4	23
Student	S iStart	3	18	7	4	4	36
	S iTopic	3	16	2	-	1	22
	Sdirect	-	2	1	1	1	5
	Question	-	1	-	-	-	1
	Statement	-	-	1	1	-	2
	Disengage	-	1	-	-	1	2
	Restart	-	2	-	-	-	2
	Move Forward (Move)	1	2	3	1	-	7
	Demonstrate (Demo)	-	2	3	1	-	6
Feel - Positive	-	-	-	-	-	0	

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Table D.1 – *Continued from previous page*

Issue Content Categories		GS	SA	UC	Other	NI	Total
# of Issues		6	23	8	5	5	47
	Feel - Negative	-		1	-	1	2
	Own	-	2	-	-	1	3
TA	TA iStart	3	5	1	1	1	11
	TA iTopic	3	7	6	5	4	25
	Diagnosis - Active	-	0	2	2	-	4
	Diagnosis - Listen	1	6	-	2	-	9
	Diagnosis - Work	-	7	4 [†]	1	4	16
	Diagnosis - Abbreviated	5	10	2	-	1	18
	TADirect	6	21	7	4	4	42
	Sinput	2	14**	3	1	2	22
	Prompt	1	4	1	-	1	7
Post-Interaction	Move Forward (Move)	5	18	7	5	4	39
	Restart	-	2	-	-	-	2
	Neither Move or Restart	-	1	-	-	-	1
	Discussion (Disc)	1	1	3	-	1	6
	Demonstrate (Demo)	2	11	4	1	1	19
	Feel - Positive	-	-	-	-	-	0
	Feel - Negative	-	3	-	-	-	3

Table D.2: Frequency results for all framework features by GTA. In the section of the SPI During the interaction only rows for which the SPI component is different from the AI component are displayed (all gray). When the components are the same, those features only get counted in the AI rows to avoid double counting.

Framework Results Across GTAs

		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
Issue Content Cate- gories	Getting Started	2	2	2	-	-	6
	Solution Approach	8	12	1	-	2	23
	Unit Conversion	1	4	2	1	-	8
	Other	2	1	1	1	-	5
	No Issue	1	1	1	2	-	5
AI-C	AI-C present	3	3	-	-	2	8
	Uncertainty (U)	-	3	-	-	1	4
	Error (E)	3	2	-	-	2	7
	Resolution (R)	-	-	-	-	-	0
AI-C	Address	1	3	-	-	2	6
	w/ Conceptual (Conc)	1	3	-	-	1	5
	w/ Procedural (Proc)	1	1	-	-	2	4
	Resolution (R)	1	2	-	-	2	5
	Functional Resolution (Rf)	-	1	-	-	-	1
AI-C	Shift	-	-	-	-	-	0
	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	1	1	-	-	-	2
	Shift	-	-	-	-	-	0

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Table D.2 – *Continued from previous page*

		GTA	GTA	GTA	GTA	GTA	Total
		2	4	5	6	7	
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
AI-CWhy	AI-CWhy present	4	2	-	-	-	6
	Uncertainty (U)	-	-	-	-	-	0
	Error (E)	2	1	-	-	-	3
	Resolution (R)	-	-	-	-	-	0
AI-CWhy	Address	2	2	-	-	-	4
	w/ Conceptual (Conc)	1	2	-	-	-	3
	w/ Procedural (Proc)	1	-	-	-	-	1
	Resolution (R)	-	2	-	-	-	2
	Functional Resolution (Rf)	1	-	-	-	-	1
AI-CWhy	Shift	-	-	-	-	-	0
	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	1	-	-	-	-	1
	Shift	-	-	-	-	-	0
AI-P	AI-P present	12	16	6	2	-	36
	Uncertainty (U)	9	7	3	-	-	19
	Error (E)	9	10	4	2	-	25
	Resolution (R)	-	1	-	-	-	1
AI-P	Address	11	13	6	2	-	32
	w/ Conceptual (Conc)	1	5	1	-	-	7
	w/ Procedural (Proc)	11	12	6	2	-	31
	Resolution (R)	6	9	6	2	-	23
	Functional Resolution (Rf)	2	1	-	-	-	3
	Shift	-	1	-	-	-	1

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Table D.2 – Continued from previous page

		GTA	GTA	GTA	GTA	GTA	Total
		2	4	5	6	7	
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
AI-P	Resolution (R)	2	1	-	-	-	3
	Functional Resolution (Rf)	1	1	-	-	-	2
	Shift	1	1	-	-	-	2
AI-PWhy	AI-PWhy present	1	1	1	-	-	3
	Uncertainty (U)	-	1	-	-	-	1
	Error (E)	-	-	-	-	-	0
	Resolution (R)	-	-	-	-	-	0
	Address w/ Conceptual (Conc)	1	-	1	-	-	2
AI-PWhy	w/ Procedural (Proc)	1	-	1	-	-	2
	Resolution (R)	-	-	1	-	-	1
	Functional Resolution (Rf)	1	-	-	-	-	1
	Shift	-	-	-	-	-	0
AI-PWhy	Resolution (R)	-	-	-	-	-	0
	Functional Resolution (Rf)	1	-	-	-	-	1
	Shift	-	-	-	-	-	0
AI-C/PWhy (COMBO)	AI-C/PWhy Combo present	2	2	-	-	-	4
	Uncertainty (U)	1	-	-	-	-	1
	Error (E)	1	1	-	-	-	2
	Resolution (R)	-	-	-	-	-	0
	Address w/ Conceptual (Conc)	-	-	-	-	-	0
AI-C/PWhy (COMBO)	<i>Continued on next page</i>						

Table D.2 – *Continued from previous page*

	GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities	4	4	1	1	1	<i>n/a</i>
# of Issues	14	20	7	4	2	47
w/ Procedural (Proc)	-	-	-	-	-	0
Resolution (R)	-	-	-	-	-	0
Functional Resolution (Rf)	-	-	-	-	-	0
Shift	-	-	-	-	-	0
AI-Resolution (R)	-	1	-	-	-	1
C/PWhy (COMBO) Functional Resolution (Rf)	-	-	-	-	-	0
Shift	-	-	-	-	-	0
Automatic (Au)	3	10	3	2	-	18
Question Generated, Answered (Q-a)	3	3	2	-	1	9
AI Creation Question Generated, Un-answered (Q-na)	2	2	-	-	-	4
Independent (In)	-	1	-	-	-	1
Collaborative (Co)	9	6	3	-	1	19
Challenge (Ch)	2	2	-	-	2	6
Inquiry Question (Qi)	6	11	3	-	2	22
SPI-C present and same as AI	1	2	-	-	1	4
SPI-C SPI-C present and different from AI	1	2	-	-	-	3
Total SPI-C	2	4	-	-	1	7
Uncertainty (U)	1	2	-	-	1	4
Uncertainty (U) - different from AI	1	2	-	-	-	3
Error (E)	-	-	-	-	-	0

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Table D.2 – *Continued from previous page*

		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
SPI-C	Error (E) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	1	-	-	-	-	1
SPI-C	Resolution (R) Incorrect - different from AI	-	1	-	-	-	1
	Address - different from AI	1	2	-	-	-	3
	w/ Conceptual (Conc) - different from AI	1	2	-	-	-	3
	w/ Procedural (Proc) - different from AI	-	-	-	-	-	0
	Resolution (R) - different from AI	-	1	-	-	-	1
	Resolution (R) Correct	-	-	-	-	-	0
SPI-C	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-CWhy	SPI-CWhy present and same as AI	1	1	-	-	-	2
	SPI-CWhy present and different from AI	-	-	-	-	-	0
	Total SPI-CWhy	1	1	-	-	-	2

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Table D.2 – Continued from previous page

	GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities	4	4	1	1	1	<i>n/a</i>
# of Issues	14	20	7	4	2	47
Uncertainty (U)	1	1	-	-	-	2
Uncertainty (U) - different from AI	-	-	-	-	-	0
Error (E)	-	-	-	-	-	0
Error (E) - different from AI	-	-	-	-	-	0
SPI-CWhy Resolution (R) Correct	-	-	-	-	-	0
Resolution (R) Correct - different from AI	-	-	-	-	-	0
Resolution (R) Incorrect	1	1	-	-	-	2
Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
SPI-CWhy Address - different from AI	-	-	-	-	-	0
w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0
w/ Procedural (Proc) - different from AI	-	-	-	-	-	0
Resolution (R) - different from AI	-	-	-	-	-	0
Resolution (R) Correct	-	-	-	-	-	0
Resolution (R) Correct - different from AI	-	-	-	-	-	0
SPI-CWhy Resolution (R) Incorrect	-	-	-	-	-	0
Resolution (R) Incorrect - different from AI	-	-	-	-	-	0

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Table D.2 – *Continued from previous page*

	GTA	GTA	GTA	GTA	GTA	Total
	2	4	5	6	7	
# of Lab Activities	4	4	1	1	1	<i>n/a</i>
# of Issues	14	20	7	4	2	47
SPI-P present and same as AI	7	9	3	-	-	19
SPI-P present and different from AI	2	3	1	1	1	8
Total SPI-P	9	12	4	1	1	27
Uncertainty (U)	7	9	3	-	-	18
Uncertainty (U) - different from AI	2	2	-	-	1	5
Error (E)	2	1	2	-	-	5
Error (E) - different from AI	-	1	-	1	-	2
SPI-P Resolution (R) Correct	-	2	-	-	-	2
Resolution (R) Correct - different from AI	-	1	-	-	-	1
Resolution (R) Incorrect	1	2	-	-	-	3
Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
Address - different from AI	1	2	1	1	1	6
SPI-P w/ Conceptual (Conc) - different from AI	-	-	-	-	1	1
w/ Procedural (Proc) - different from AI	1	2	1	1	1	6
Resolution (R) - different from AI	-	1	-	-	1	2
Resolution (R) Correct	-	-	-	-	-	0

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Table D.2 – *Continued from previous page*

		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
SPI-P	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incor- rect	-	-	-	-	-	0
	Resolution (R) Incor- rect - different from AI	-	-	-	-	-	0
SPI- PWhy	SPI-PWhy present and same as AI	1	-	1	-	-	2
	SPI-PWhy present and different from AI	-	1	1	1	-	3
	Total SPI-PWhy	1	1	2	1	-	5
	Uncertainty (U)	1	-	-	-	-	1
	Uncertainty (U) - dif- ferent from AI	-	-	-	-	-	0
SPI- PWhy	Error (E)	-	-	-	-	-	0
	Error (E) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incor- rect	-	-	-	-	-	0
	Resolution (R) Incor- rect - different from AI	-	-	-	-	-	0
	Address - different from AI	-	1	1	-	-	2
w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0	

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Table D.2 – *Continued from previous page*

		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
SPI- PWhy	# of Lab Activities	4	4	1	1	1	<i>n/a</i>
	# of Issues	14	20	7	4	2	47
	w/ Procedural (Proc) - different from AI	-	1	1	-	-	2
	Resolution (R) - differ- ent from AI	-	1	1	-	-	2
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	1	-	1
SPI- PWhy	Resolution (R) Incor- rect	-	-	-	-	-	0
	Resolution (R) Incor- rect - different from AI	-	-	-	-	-	0
	SPI-C/PWhy present and same as AI	-	-	-	-	-	0
SPI- C/PWhy (COMBO)	SPI-C/PWhy present and different from AI	-	-	-	-	-	0
	Total SPI-C/PWhy	-	-	-	-	-	0
	Uncertainty (U)	-	-	-	-	-	0
	Uncertainty (U) - dif- ferent from AI	-	-	-	-	-	0
	Error (E)	-	-	-	-	-	0
	Error (E) - different from AI	-	-	-	-	-	0
	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incor- rect	-	-	-	-	-	0

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SPI-

Table D.2 – *Continued from previous page*

C/PWhy (COMBO)		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
	# of Lab Activities	4	4	1	1	1	<i>n/a</i>
	# of Issues	14	20	7	4	2	47
SPI- C/PWhy (COMBO)	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
	Address - different from AI	-	-	-	-	-	0
	w/ Conceptual (Conc) - different from AI	-	-	-	-	-	0
	w/ Procedural (Proc) - different from AI	-	-	-	-	-	0
	Resolution (R) - different from AI	-	-	-	-	-	0
SPI- C/PWhy (COMBO)	Resolution (R) Correct	-	-	-	-	-	0
	Resolution (R) Correct - different from AI	-	-	-	-	-	0
	Resolution (R) Incorrect	-	-	-	-	-	0
	Resolution (R) Incorrect - different from AI	-	-	-	-	-	0
TAFI - C	AI present - TAFI same	-	2	-	-	2	4
	AI present - TAFI mostly same	1	1	-	-	-	2
	AI present - TAFI different	2	1	-	-	-	3
	AI present - TAFI absent	1	-	-	-	-	1
	AI absent - TAFI present	-	1	1	-	-	2
	AI absent - TAFI absent	9	9	6	2	-	26

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Table D.2 – *Continued from previous page*

	GTA	GTA	GTA	GTA	GTA	Total	
	2	4	5	6	7		
# of Lab Activities	4	4	1	1	1	<i>n/a</i>	
# of Issues	14	20	7	4	2	47	
<hr/>							
Total TAFI-C present	3	5	1	-	2	11	
<hr/>							
TAFI - CWhy	AI present - TAFI same	-	-	-	-	0	
	AI present - TAFI mostly same	-	-	-	-	0	
	AI present - TAFI different	1	2	-	-	3	
	AI present - TAFI absent	3	-	-	-	3	
	AI absent - TAFI present	-	1	-	-	1	
	AI absent - TAFI absent	10	17	7	4	2	40
	Total TAFI-CWhy present	1	3	-	-	-	4
<hr/>							
TAFI - P	AI present - TAFI same	6	9	3	2	-	20
	AI present - TAFI mostly same	3	2	3	-	-	8
	AI present - TAFI different	3	2	-	-	-	5
	AI present - TAFI absent	-	3	-	-	-	3
	AI absent - TAFI present	1	2	1	2	-	6
	AI absent - TAFI absent	1	2	-	-	2	5
	Total TAFI-P present	13	15	7	4	-	39

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Table D.2 – *Continued from previous page*

		GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities		4	4	1	1	1	<i>n/a</i>
# of Issues		14	20	7	4	2	47
TAFI - PWhy	AI present - TAFI same	-	-	-	-	-	0
	AI present - TAFI mostly same	-	-	-	-	-	0
	AI present - TAFI dif- ferent	-	-	-	-	-	0
	AI present - TAFI ab- sent	2	2	1	-	-	5
	AI absent - TAFI present	-	2	1	-	-	3
	AI absent - TAFI ab- sent	11	10	5	2	2	30
	Total TAFI-PWhy present	-	2	1	-	-	3
TAFI - C/PWhy COMBO	AI present - TAFI same	-	1	-	-	-	1
	AI present - TAFI mostly same	-	-	-	-	-	0
	AI present - TAFI dif- ferent	1	-	-	-	-	1
	AI present - TAFI ab- sent	-	-	-	-	-	0
	AI absent - TAFI present	-	5	-	2	-	7
	AI absent - TAFI ab- sent	-	-	-	-	-	0
Total TAFI-C/PWhy present	1	6	-	2	-	9	
Get	7	10	6	3	1	27	

Continued on next page

TAFI -
Student
Re-
sponse

Table D.2 – Continued from previous page

	GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities	4	4	1	1	1	<i>n/a</i>
# of Issues	14	20	7	4	2	47
Rectify	-	5	1	2	1	9
Redirect	1	4	1	-	-	6
Resolution (R)	10	16	7	4	2	39
Not Resolved - Full Match w/ AI	1	1	-	-	-	2
Not Resolved - Partial Match w/ AI	1	1	-	-	-	2
Not Resolved - Full Mismatch w/ AI	2	1	-	-	-	3
Not Resolved - Blank	-	1	-	-	-	1
Beginning Issue						
AI	3	5	2	-	2	12
SPI	3	3	-	-	-	6
TAFI	4	2	-	-	-	6
Other	4	11	4	4	-	23
Student						
S iStart	8	16	7	3	2	36
S iTopic	6	11	3	-	2	22
Sdirect	1	1	-	1	2	5
Question	-	-	-	-	1	1
Statement	-	1	-	1	-	2
Disengage	1	-	-	-	1	2
Restart	1	1	-	-	-	2
Move Forward (Move)	1	2	3	-	1	7
Demonstrate (Demo)	2	1	2	-	1	6
Feel - Positive	-	-	-	-	-	0
Feel - Negative	-	2	-	-	-	2

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Table D.2 – Continued from previous page

	GTA 2	GTA 4	GTA 5	GTA 6	GTA 7	Total
# of Lab Activities	4	4	1	1	1	<i>n/a</i>
# of Issues	14	20	7	4	2	47
Own	1	1	-	1	-	3
TA						
TA iStart	6	4	-	1	-	11
TA iTopic	8	9	4	4	-	25
Diagnosis - Active	2	2	-	-	-	4
Diagnosis - Listen	3	4	1	1	-	9
Diagnosis - Work	7	4	3	2	-	16
Diagnosis - Abbreviated	2	10	3	1	2	18
TAdirect	13	19	7	3	-	42
Sinput	6	14	1	1	-	22
Prompt	2	4	-	1	-	7
Post-Interaction						
Move Forward (Move)	12	15	6	4	2	39
Restart	-	2	-	-	-	2
Neither Move or Restart	1	-	-	-	-	1
Discussion (Disc)	-	3	1	1	1	6
Demonstrate (Demo)	7	5	4	1	2	19
Feel - Positive	-	-	-	-	-	0
Feel - Negative	2	1	-	-	-	3

Appendix E

Background Questionnaires

E.1 GTA Background Questionnaire

1) Please circle your year as a grad student.

1st year 2nd year 3rd year 4th year 5th year 6th+ year

2) Are you an international student?

Yes No

3) Please list the physics courses for which you have been a teaching assistant (NOT only a grader) and the number of semesters you were a TA each course.

Physics Course	# Semesters TAing Course

4) Do you have any teaching experience outside of being a teaching assistant at NCSU (eg: teaching high school, etc.)? If so, please briefly describe your experiences.

5) Prior to graduate school, how many years have you studied physics? (please include primary, secondary, and post secondary school if applicable)

6) Please rank the order of importance of each of your main graduate school activities by putting a 1, 2 or 3 (1=most important, 3=least important).

Classes	Being a TA	Research

7) Please rate your comfort being a TA (labs or tutoring) for the following topics:

Kinematics

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Forces

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Momentum

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Energy

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Angular Momentum

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Torque

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Energy Quantization

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

Multi-particle

Systems

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

E.2 Student Background Questionnaire

1) Please circle one

Female Male

2) Please circle your year as a grad student.

1st year 2nd year 3rd year 4th year Over 4 years

3) Please list all physics classes you have taken prior to this one (please include high school **and** college courses). Please also include the length of the course (eg: 1 semester, 1 year)

Physics Course	Length of Course

4) How comfortable do you feel with your overall knowledge of introductory physics so far (specifically mechanics)? (please circle one)

Very Uncomfortable 1 2 3 4 5 6 7 8 9 10 Very Comfortable

5) Please circle the mathematics courses you have taken including any current enrollment this semester.

Algebra	Trigonometry	Pre-Calculus	Calculus 1 or equivalent	Calculus 2 or equivalent	Higher than Calc 2
---------	--------------	--------------	-----------------------------	-----------------------------	-----------------------

6) The role I most prefer taking on in a group is: (please circle one)

Manager

Recorder

Skeptic

Appendix F

Data Collection and Processing Methods

Below I detail the process of selecting equipment for data capture, setting it up, and processing the output to create a single video data file for analysis.

F.1 Data Collection Methods

F.1.1 In Vivo Data Collection (2010 and 2012 Spring Semesters)

Working within a lab classroom provided limitations on the equipment I could use, the setup design, and the locations within the classroom in which I could set up equipment. Since the lab portion of the course is held in classrooms across campus from the Qualitative Education Research Lab (QERL), I focused on a setup that would allow for easily transportable equipment. Following Weatherford (2011), I wanted the setup to capture the general actions of the students, their body language, and their facial expressions where possible; the work they wrote on their whiteboard; and their computer screens as they worked through an activity. I describe this equipment and setup below. I was present for all data collection to monitor equipment but remained in an unobtrusive location in the classroom.

Camera 1 - General Video Camera

I needed at least two cameras, and computers to operate them, to capture everything I wanted. The first camera was an over-the-shoulder video camera which was mounted on a tripod and connected to a Mac Mini. This camera was placed so that it would not only capture what was needed, but would also remain unobtrusive to the subjects *and* unobstructive to the rest of the students. This limited the possible locations to the counter at the back of the lab room. From the position on the back counter I could aim the video camera to capture the group at the desired table as seen in Figure F.1. This position was the least obtrusive to those students, and it allowed me to focus in on their work if needed. However, I could not capture the students' facial expressions much of the time. I also could not capture the GTAs' actions if they spoke with students while leaning against the counter, out of range of the viewfinder. I have taken these limitations into consideration when analyzing the data.

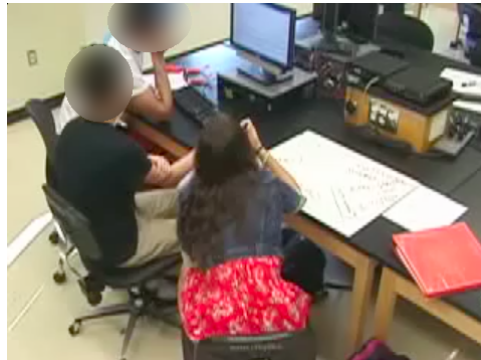


Figure F.1: The group as captured by the over-the-shoulder camera.

Camera 2 - Overhead Camera

The second camera recorded the overhead view. In the QERL, there are overhead cameras mounted in the ceiling for data capture of whiteboard work. Since I do not have this equipment in the regular lab classroom, one of the cameras had to be small and light enough to easily hang

from the ceiling to capture whiteboard work. I chose a Logitech webcam for this purpose. This camera hung high enough to remain unobtrusive to the students beneath it and also captured clear recordings of their work. The Logitech camera uses PC compatible software, and so I connected it to the lab computer the students would be using. This eliminated the need for a second operating computer and several USB extension cables. The view from this camera can be seen in Figure F.2.

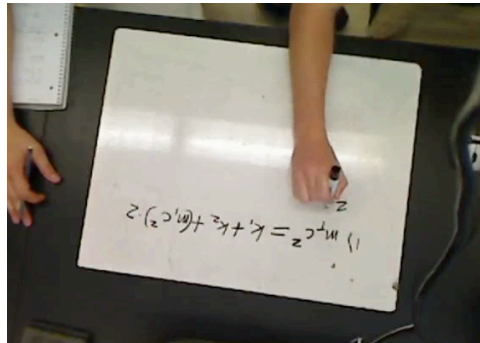


Figure F.2: The whiteboard work as captured by the overhead camera.

When I took data in 2010, I was able to use the Logitech software along with the camera. However, in 2012, Microsoft security updates led to continuous problems using the Logitech software. Early on in data collection, I switched to a free version of Debut Video Capture Software from NCH Software.¹ This software worked perfectly for what was needed, and no further problems arose.

Camera 3 - Screen Capture

Finally, BBFlashback Express² screen capture software was loaded onto the computers the students use. This software allows me to control several features of the capture. For instance, I set the frame rate to 5fps since I do not need to capture smooth motion. This produces a

¹<http://www.nchsoftware.com/capture/index.html>

²<http://www.bbsoftware.co.uk>

smaller, more manageable file size for processing. Another helpful feature is mouse tracking. Selecting for mouse tracking produces a video in which the mouse stays highlighted in yellow throughout the video. This makes it easier to follow along during analysis. Figure F.3 shows the screenshot view. This form of capture was not used on the data from the 2010 Spring semester study during the lab activity used.

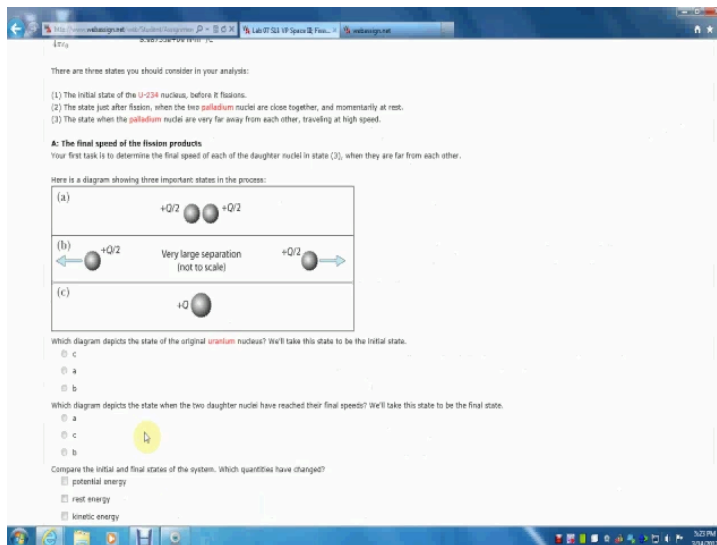


Figure F.3: The PC work as captured by the screen capture software - BBFlashback.

F.1.2 In Vitro Data Collection (Fall 2010 Semester)

As mentioned above, I also chose to use data that had already been collected for an earlier study (Weatherford, 2011). This was an in vitro study, utilizing the QERL rooms and equipment. The QERL room used in the 2010 study held four lab groups at one time, reducing the student population of the labs by 50%.

This data was also collected using the same three forms of capture as the other studies used. However, student and GTA faces were also captured with a forward facing webcam. Figure F.4 shows view from the webcam. A Logitech webcam was also placed in an upper corner of the

room to capture the whole class at once. The GTA then wore a small microphone to record his voice with that perspective. I used data from that angle in one lab when the face capture webcam failed. Figure F.5 shows the view from that camera.



Figure F.4: The group as captured by the webcam.



Figure F.5: The entire class gathered in the in vitro study. This was used only if the face capture failed. The group observed in this image is the one at the bottom, closest to the camera.

F.2 Video Data Processing

Each camera produced a separate video file with differing file types. The goal in processing the files was to create one video containing all relevant video data from all three sources for each individual lab. This process involved converting video files, syncing them, splicing them together, and re-recording them into one video. I describe this process in further detail below.

Each video file I initially collected had a unique filetype, codec, and window size. The over-the-shoulder video resulted in a .mov file. The overhead video was initially a .wmv file, and the screen capture was in .fbr format. The first task in processing, then, was to convert each file to the same format and codec. While this was a fairly easy task, I had to be vigilant about retaining video quality through this first conversion. I chose to convert all videos to H.264 codec and export them ultimately as .mov files. This selection allowed for a relatively fast conversion while still retaining video quality. I executed this process on all videos using a combination of Handbrake³ and Quicktime Pro.

Once all files were in the same format, I had to sync them. This was the most difficult step of the process since each video took uniquely different footage, and only two of the three videos recorded sound. First, I viewed the general over-the-shoulder video and looked for a place in that video in which the image on the screen changed dramatically. For instance, when the students pulled up Internet Explorer from a Windows desktop, I could easily see the change in colors. Student behaviors also provided clues as to where the students were in a problem, so most likely which screen windows were changing. I then looked for that same change in the screen captured video. Within Quicktime, I used the cursor arrows to count the exact frame at which the change began. This was marked as the syncing time for these two videos.

I then did a separate syncing for the over-the-shoulder video and the overhead video. I scanned the over-the-shoulder video for a particular obvious movement performed by a student within the range of the overhead video. I then checked the audio to ensure I was within the same patch of video in both videos. Finally, I used Quicktime to move through each frame to

³<http://handbrake.fr/>

match up exact points of motion. Exact points of motion are not always as obvious as changes in the PC screen, and so there might be a slight difference in syncing between the overhead and the other two videos. However, this variation should still be on the order of only a few frames.

Finally, I used each of the two separate syncs to calculate the appropriate times to begin each video such that they were matched. In this way, all three videos were brought into sync to be further processed.

Once the videos were synced, they were imported to Final Cut Pro (FCP) for further processing. The goal with this step was to combine the overhead video with the screen captured video to produce one video that switched between the two kinds of data depending on the students' present focus. I used the synced times to align the videos in FCP and set the screen capture video to be the default video. From there I searched for places in the overhead video in which students were writing on the whiteboard or gesturing significantly over it. I cut these pieces out of the overhead, cut the same pieces out of the screen capture video and pasted the overhead pieces into the spaces in the screen captured video. This video was then exported as a Quicktime Movie.

The final processing move combined the over-the-shoulder video with this new combo movie. I wanted to make sure I could clearly see both videos playing simultaneously. I first attempted to use Mac's ScreenFlow program to accomplish this by playing both videos and capturing them as they played on the desktop. To use this program, I opened the videos in Quicktime7 as this program permits playing both videos simultaneously. I synced the videos using the previous calculations and then began running ScreenFlow and playing the videos. While the capture was successful, I was underwhelmed at the low frame rate - choppiness - of the final video. I attempted to make adjustments such as shrinking the video screens and lowering overall quality to encourage a higher frame rate but was still unsuccessful in producing a high enough frame rate to consider the video worthwhile.

I then turned to Quicktime's screen capture to attempt the same operation (Note: the ScreenCapture was done with Quicktime Pro while the videos stilled played in Quicktime7).

Quicktime produced a final video that was acceptable. The software did still decrease the frame rate of the final video but not enough to warrant it useless or even bothersome while viewing. This step completed video processing and left me with the final videos that were used for all analysis. Figure F.6 shows a representation of the final video.

In Vitro Data Processing

Data processing was slightly different for the in vitro study data. This was due only to the difference in which cameras collected audio feeds. In the in vivo study, the over-the-shoulder video camera also collected the audio feed. In the in vitro study, the overhead camera collected the audio feed. This difference required some modifications to how I synced the various videos in FCP. Other than syncing, video processing was very similar to what I previously describe. The final video file image from this data can be seen in Figure F.7.

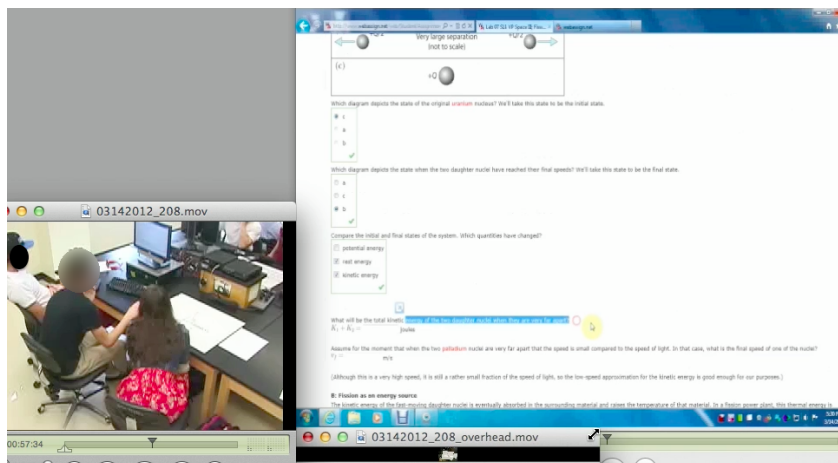


Figure F.6: Final video from the in vivo after processing was completed.

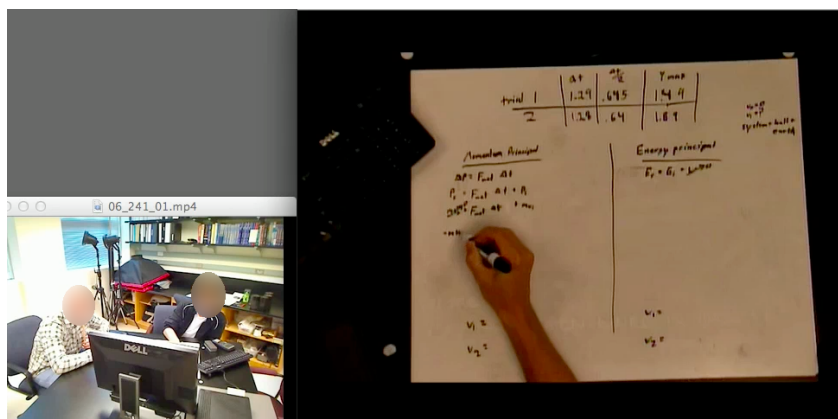


Figure F.7: Final video from the in vitro data after processing was completed.

F.3 Limitations and Problems with Data Collection and Processing

Learning the Ropes: Week 1 of Pilot Study Data Collection

Beginning the pilot study, the intent was to focus largely on the GTAs' behaviors and less so on the students' specific work. Thus I decided against including screen capture software in that week of data collection, even though I had left room for it in the IRB.

It was not until another researcher wanted to gather screen data that I implemented the screen capture software and began collecting that data. Unfortunately, about half of the data used in this study is from that first week of pilot study data collection. Thus, I do not have computer work captured for roughly half of the data.

While I lose the details of the students typing, I am able to interpret quite a bit from their verbal expressions. In this particular week, students' computer use was limited to filling in a table and answer boxes on WebAssign. Due to this restriction, their verbalizations, and the fuzzy view of the screen captured with the back counter video camera, I was able to detect whether students were filling in correct or incorrect responses, even when I could not tell exactly what those response were.

Another problem with this first week of data capture did not present itself until I reviewed

the data for processing. In this particular week, the overhead cameras stopped recording partway through the lab period in two of three labs. It stopped at different times in each lab, and the times did not seem tied to a particular occurrence. Thus, I lost some overhead footage for those labs.

With this loss, I look to student verbalizations and gestures to interpret what they might be writing on the whiteboard. While I may not know the specific numbers being written down, I can tell that sweeping arm motions in combination with certain discussion indicates students are drawing a diagram and identifying particular pieces of their diagram. Finally, some of the students whiteboard work is captured sporadically when the video camera zooms in on their work. This was only worthwhile when the students had written quite a bit on their whiteboard and then moved out of the way so it could be captured. Thus, the shots of the whiteboard work are subject to its complexity and visibility.

Camera Position for the In Vitro Study

In the QERL, four cameras are set up to capture the whiteboard work of the four different groups in the study. The camera positions in the lab were controlled via a joystick in an adjoining room. They were each manipulated throughout the lab period by a researcher who attempted to capture as much whiteboard work as possible. However, with all the minor adjustments needed to follow the writing of the students, it was not always possible to capture what each group wrote through the entire period for every lab. Thus, some of the data from these labs lacks observable whiteboard work. I have pieced together interpretations of what students are doing where I can, using their verbalizations.

Occasionally in these labs, the face-capturing webcams failed, leaving no videos to watch the actual people in the group. In these instances, I used the whole-class video and watched the group from a distance. After selecting the specific data for the project from these videos, I was left with one video that required the whole-class video.

Video Capture in a Darker Room

The final problem with the data was identified only after processing all of it and reviewing the final videos. This issue affected videos in both the in vivo and in vitro labs and is likely due to a problem (or possibly a missed setting) in the Logitech camera software.

During the lab focused on spectra, the GTA turned off the lights for students to view specific lamps through diffraction gratings. Once the lights were out, the video of the darkened room played at an accelerated rate, preventing me from playing the multiple videos together in sync. This happened in all but one of the spectra labs. In the lab in which the video turned out normal, I used Debut video capture software to capture the recording. All other labs used the standard Logitech software.

Processing these videos using the above methods did not pose any problems, and I was able to sync specific times in the video. I was also able to find the appropriate places to splice together footage from the Logitech camera and screen capture as both videos showed relatively the same amount of footage and did in fact capture the entire lab. However, once synced and spliced, the video segments from the Logitech capture played back at an accelerated rate of 2x its partner. Thus, I could get all the data I needed from this video, but could not watch it concurrently with its partner video (except in the case of using Debut software).

This ended up affecting two lab groups, one in the in vivo lab, and one in the in vitro lab. In the in vivo lab, the whiteboard work was the video that played too quickly. To gather useable data from this, I played back the video, paused when the whiteboard work was displayed, and took a picture of that work. I then later referenced these pictures when coding and analyzing the data.

In the in vitro lab, the whole-class video showing the group at a distance (for the one lab in which I used the whole-class video) played too quickly. In this case I reviewed the video and decided to ignore the view of the group altogether. From the review, this perspective could not provide the kinds of detail needed without being well synced with its partner.

There are limitations to what can be interpreted from the data due to this problem, and

I recognize that this particular problem could probably have been fixed with the appropriate software and editing skills. However, the limitations I encountered are minor in comparison to the time it would have taken to fix the videos. Thus, I decided to leave the videos as they were.