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UNIVERSITY OF CALIFORNIA

Los Angeles

The Interpersonal Organization of Failure and Knowledge

in Mathematics Tutoring

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Education

by

David Jeffrey DeLiema

2015

ABSTRACT OF THE DISSERTATION

The Interpersonal Organization of Failure and Knowledge

in Mathematics Tutoring

by

David Jeffrey DeLiema

Doctor of Philosophy in Education

University of California, Los Angeles, 2015

Professor Noel D. Enyedy, Chair

The ideas students have about what causes math failure are known to impact their motivation. This dissertation throws light on how attributions of failure are negotiated during math tutoring at a non-profit STEM-based after-school program. The study employs methods of interaction analysis on a small number of cases to qualitatively document how tutor-student dyads co-construct stories about failure. The project addresses the theoretical relationship between students and tutors' enacted responses to failure and their enacted knowledge-construction practices. I argue that responses to failure involve constructing obstacles, blaming causes of obstacles, and intervening to resolve obstacles, which take place as part of public practice. How students recruit sources of knowledge (perception, reasoning, introspection, memory, and testimony) in knowledge-construction practices, and how they tell stories about breakdowns in those practices are core concerns of the dissertation. By understanding the interactional mechanics of failure, the study can inform discourse-level interventions in the future.

The dissertation of David Jeffrey DeLiema is approved.

William A. Sandoval

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Charles Goodwin

Francis F. Steen

Noel D. Enyedy, Committee Chair

University of California Los Angeles

2015

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Acknowledgements

This dissertation came from thousands of struggles that my mentors and peers shrugged off and helped me stamp out. The community at UCLA has simply provided a phenomenal space for learning and discovery. I must start by thanking my advisor, Noel Enyedy, who encouraged me to ebb and flow through multiple intellectual traditions, challenged me at each step, provided honest assessments of my work, and introduced me to the ideas that undergird this dissertation—he, more than anyone else, knows how much I've shape-shifted in graduate school, and I cannot thank him enough for encouraging me along the way.

I would probably be a lawyer were it not for Francis Steen, who has been the most intellectually motivating and supportive mentor a young scholar could ask for. The first thing Francis taught me was how to pay attention to cognition—specifically to how long I could imagine a motionless apple in my imagination—and that approach of attending to the mundane has stuck with me since. Thank you.

Bill Sandoval and Chuck Goodwin each shook the roots of my intellectual world. Bill introduced me to epistemology and gave it verve. Just at the point where Bill and I had dug ourselves into an intellectual spider hole—despite Bill's efforts to put an end to my thought experiments on how I *know* how to open a can of soup—I walked into Chuck Goodwin's lab. Chuck taught me how to attend to the organization of human action, layer by layer, and offered tools and concepts to realize many of my goals in education research. They have both been encouraging, honest, and brilliant mentors.

To the tutors, students, and staff at the after-school program who made this dissertation possible, I thank you and promise that I will give my all to help turn this small study into something that can motivate schools to become places of resilience in the face of failure.

what you learn, this dissertation is living proof of your wisdom. To all of my friends—thank you, thank you, thank you.

Most importantly, I wish to thank my wife, Marti, my companion in everything throughout graduate school. If I can become even half as productive and brilliant as you, I'll be proud.

Vitae

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Chapter 1
Thinking Publicly and Co-operatively About Failure

1.1   Goals of the dissertation

Given the structure of public education, failure for many students is ubiquitous. Despite that the high-school dropout rate has declined over recent decades, 2.2 million U.S. students in 2013 abandoned their formal education before graduating (US Census Bureau, 2013). That is about 7% nationally. In Los Angeles and other urban districts, the dropout rate is disproportionately high in non-dominant Hispanic and African-American communities (California Department of Education, 2013). And in key mathematics courses—one of the gatekeepers to college access— failure rates are alarmingly high. In 2004 in Los Angeles, 44% of high school students failed beginning algebra and 17% received letter D grades (Helfand, 2006). Apart from terminal cases of school or course failure, students experience delays, moments of confusion, and frustration in daily efforts to generate math knowledge valued in school.

How students think about routine and terminal failure and how they respond to failure matters. Research shows that students' ideas about the causes of failure are tightly connected to perseverance (Weiner, 1983), and perseverance is a critical component to success in school. One core finding from this line of research is that students who attribute failure to effort over ability have higher levels of motivation (Graham, 1991). To provide an example of the implication of this finding, teachers have an inclination to attribute girls' math failures to ability and boys' math failures to effort (Espinoza, Fontes, & Chavez, 2013), setting up divergent motivation across genders.

It seems likely that these post-hoc attributions of failure have their roots in the immediate visceral experience of particular failure events, including small moments of struggle in mathematics that students experience on a daily basis. My dissertation asks: How do students (and their teachers) respond to failure—in the very moment that obstacles to learning arise? Educational researchers have conducted relatively little systematic research into how people—in culturally routine environments pursing goals they value—work together in their talk and activity to understand what counts as failure, where it comes from, and what can be done about it. In prioritizing social practice, I aim to understand the public process through which multiple people *co-operate* (Goodwin, forthcoming) on failure, assembling resources within each other and their environments to understand breakdowns in learning and resolve them.

With schools more frequently asking students to sustain grit across significant school challenges, against the backdrop of cultural and cognitive processes that transform failure into a negative experience, the need to document the social origins of attitudes about and reactions to failure is acute. A study of the social practice of responses to failure can inform discourse-level interventions aimed at nurturing sustainable orientations to failure.

1.2   Making failure public

We have all withheld details about or resisted acknowledging a moment of failure, and yet enough about our shortcomings leaks into social interaction for the experience of sharing failure to be meaningful. Whether through stories, body language, casual conversation, or collaborative activity, people routinely make failure known to one another. Film, literature, news media, and video games even tend to operate on the principle that stories that engage audiences focus on characters with meager resources attempting to overcome towering obstacles (Abbott, 2008; Bruner, 1991; Herman, 2009; Steen, 2005)—a narrative tradition that systematically turns failure

into entertainment. Without struggle, or the probability of struggle, the story may not be worth telling. This action of moving failure out of private experience and into the light of day for public consumption and reflection permeates human society.

Formal schools in particular structure classroom activity in a way that places students' failures in public view of other students and teachers. At Success Academy charter schools in New York City, for example, teachers display students' quiz scores on colored charts in public hallways, on which students with low scores land in the red zone (Taylor, 2015). In less extreme cases, students provide erroneous ideas during whole class discourse or on homework assignments. With failure on display, resolutions to obstacles take place in view of other students in the classroom, or at least between a teacher and student. This social window into failure might seem surprising given that failure exacts a steep emotional cost—why bring onto the interpersonal plane something so aversive? One 4th grader who participated in this dissertation captures the cascade of pressures following failure:

> "I was thinking 14.4 is 16...but [the tutor] was like, "No!" And I was like, "What? Ahh. This is so confusing." And then once I get it wrong, my mind is going to be thinking, "This is hard"...And then I start getting distracted ughhhhh...and when I get distracted I feel like, when I get it wrong, it feels like I lost twenty minutes, like if twenty minutes just went super fast...And I'm not going to go to break time when I want to...I start worrying about all the homework I have, plus thirty minutes [of reading], and then all the multiplication sheets."

This student weaves together a narrative in which a wrong answer on homework triggers confusion, distraction, and stress, setting in motion worries about loss of relief and as-yet-untouched homework. The failure story is precise and descriptive, not to mention evocative

emotionally, and it begs the question of what happened when the obstacle arose during the tutoring session. How did the student together with his tutor navigate the process of finding, blaming, and intervening around the obstacle?
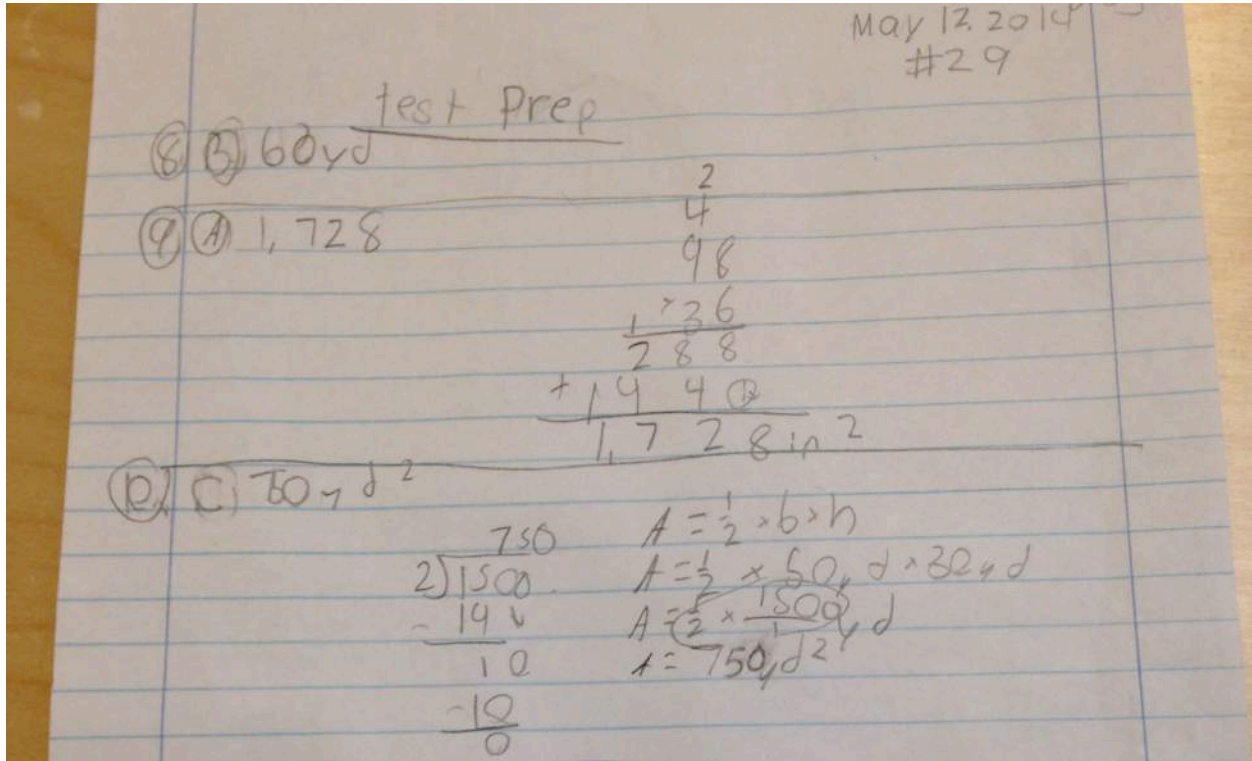
Figure 1: The 4th grader's math assignment from earlier that afternoon.

For now, I do not intend for this question to draw attention to irregularities between the student's post hoc version of the failure event and the dyad's actual earlier response to the failure event, but rather, to honor the initial failure moment in its own right, to see how students and tutors react when obstacles arise on math homework (Figure 1).

1.3 How students experience failure

In the course of mathematics learning, students and teachers encounter frequent obstacles to progress. Time constraints, distraction, exhaustion, difficulties with memorization, lack of conceptual knowledge, and even fear of failure can hamper, delay, or terminate learning. When

obstacles to learning become apparent, students and teachers can respond in two ways, drawing attention to the past and/or the future. Thoughts about the past involve blaming prior events for causing the obstacle. *I was running low on energy, my teacher hates me, these concepts are too hard*. Thoughts about the future involve planning interventions to curb the obstacle. *Try-try-try again, look at a textbook, pay attention tomorrow in class*. The process of finding, blaming, and intervening in the context of struggle creates the route through which students and teachers think through and act on failure: What counts as failure, where does failure come from, and what can students do about it?

Thoughts about failure, and the actions students and teachers take to address failure, are important because they shape students' motivation (Dweck, 1991; Weiner, 1983), thoughts about their own math identity and potential (Heyd-Metzuyanim, 2015), and plans for how to learn (Moschkovic, 1996). At first blush, common life experiences, even cultural mantras and academic theories, remind us that failure need not be experienced as universally terminal. And yet students' experiences of failure are frequently so negative that they shut down (Holt, 1964), lose agency (Weiner, 1983), and develop low self-efficacy (Bandura, 1982) and learned helplessness (Abramson, Seligman, & Teasdale, 1978). In contrast, some individuals in some situations can leverage failure to overcome short-term struggles and foster long-term grit (Duckworth, Peterson, Matthews, & Kelly, 2007; Graham, 1991). Educational researchers have even generated empirical evidence that "failure," when supported with responsive scaffolding, amounts to high-quality learning (Kapur, 2008).

The upshot is that the following contradiction has started to unfold in school: Students must fail often and work hard as they continue to fail, and yet students fear failure and develop pernicious ideas about their own potential as a result. Schools more and more frequently invite

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students to wield grit to curb failure, even to seek out failure as a viable support for learning. To provide another immoderate example from the Success Academy charter school network in New York City, teachers send students falling behind in academics to the school's local "effort academy," an after-school session that places a grit-based spin on traditional detention (Taylor, 2015). The message is that when students fail, they need to apply persistent effort to bounce back. The value of grit, which some place alongside other noncognitive skills such as self-control, curiosity, and conscientiousness, has received considerable attention in popular books about education (e.g. Tough, 2012)—and buoys the thesis from a *New York Times Magazine* article that we are living in the "Failure Age" (Davidson, 2014).

And yet despite that teachers and students may broadly recognize that failure is productive, we know that students concede after encountering obstacles (Boaler & Greeno, 2000)—whether because of anxiety and low self-efficacy (Hoffman, 2010), lack of mathematics identity (Heyd-Metzuyanim, 2015), or conceptual misunderstandings (Brown & Quinn, 2007)—and have no evidence to date that schools can teach grit (Duckworth & Gross, 2014). In addition, the positive impact of interventions focused on helping teachers attribute failure to effort have been found to languish over time (Espinoza, Fontes, & Chavez, 2013). Maybe most importantly, grit-based interventions skirt the challenge of addressing underlying misconceptions about ability and blur the distinction between productive and unproductive effort.

In broad strokes, interventions oriented toward grit attempt to change how individuals experience failure without having a deep understanding of how failure manifests in social settings. I aim for this dissertation to offer insight into the interpersonal constitution of failure, with the long-term goal of helping students and tutors productively talk about failure and respond to failure in live conversation.

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1.4   The social construction of failure

A comprehensive understanding of the interpersonal construction of failure would come only from a multi-pronged effort that bridges emotion, motivation, learning, society, cognition, and social interaction. At the least, educators need to understand students' *thoughts* and *actions* surrounding failure: How do learning communities think about failure and how do learning communities respond during failure? Educational researchers have conducted extensive research into the former topic. Their findings suggest that how students and teachers explicitly reflect on failure can shape learning and motivation (Weiner, 1983). However, we know considerably less about tacit reactions to math failure in the moment that obstacles arise, save recent qualitative projects that have informatively documented the situated experience of failure (Esmonde & Langer-Osuna, 2013; Heyd-Metzuyanim, 2015).

The question that I address in this dissertation is broad and targets mathematics learning: How do math tutors and students respond in the moment, through their public practice of talk and action, to learning obstacles? This question calls for understanding the routine practices through which teachers and students describe an action as failure, publicly document causes of that failure, and discuss plans to intervene to resolve the obstacle, including considerations of how these processes influence one another.

Why draw attention to a math classroom's enacted, public practice in response to failure? A long tradition of situated perspectives on mathematics learning has focused on math knowledge and learning as social practice (Lave, 1988; Moschkovic, 1996; Nasir, 2002), such that students engage in "*trajectories of participation* in the practices of mathematical discourse and thinking" (Boaler & Greeno, 2000, p. 172, authors' original italics). To understand mathematics failure, we have to watch students as they engage with talk, body, physical

materials, and other people to carve a specific pathway for engaging with mathematics (Roschelle, 1992). Moreover, a focus on public practices that take place even without the presence of a researcher lays bare the mechanics by which communities respond to failure, opening up the possibility to intervene in the ongoing work of the community. Instead of asking participants to engage in an activity for researchers, the researchers engage in an activity that participants pursue, in the service of better understanding that practice. If personal narratives about failure arise from the social construction of in-the-moment failure, then this work can throw some light on aspects of mathematics-based thinking, including math identity, resilience, and self-efficacy.

1.5   Overview of the dissertation

I develop two contributions to research on mathematics failure, one focused on the social process through which participants attribute causes to failure and another on the concept of math knowledge/ability. First, this dissertation (1) describes how math tutors and elementary school students collaborate to construct attributions of failure in their moment-to-moment discourse. Second, this dissertation presents (2) a situated account of the nature of knowledge in mathematics as the contact point between multiple epistemic resources.

Looking across both contributions, I argue that knowledge develops as a result of multiple internal and external streams of influence, and that stories about moments when students fail to construct knowledge can present impoverished accounts of what caused the math struggle. By giving full credit to the layers of epistemic resources that amount to knowledge, we also open up the possibility that stories about failure can throw light on interactions between finger-grained failure points. Making failure stories more comprehensive, nuanced, and precise matters because students and tutors could become more aware of the epistemic resources that

drive knowledge construction in order to find inexpensive and effective interventions when knowledge construction fails. Because failure stories are often constructed between people and in open communication channels in the classroom, educators should see them as plausible, maybe even economical, practices that teachers and students could modify to better support learning.

1.6   Definitions of core concepts

Three concepts that weave through this dissertation—failure, epistemic cognition, and understanding—warrant defining up front. Whereas researchers, educators, and students often construe failure as terminal, I adopt a more liberal understanding of the term. I view *failure* (or obstacles) in math tutoring sessions as occasions in which students do not satisfy the epistemic aim at the after-school center of accurately finishing math homework. That is, any time students perform an incorrect math calculation, become distracted from their work, or do not know what next math action to perform—and participants make relevant those actions as obstacles—then students have experienced what their learning community considers to be a barrier (however small) to achieving complete and accurate homework.

I study *epistemic cognition* from the perspective of sources of knowledge, which I define as the resources participants recruit during math activity to arrive at a knowledge claim (e.g. *I need to take the reciprocal of this fraction*). The knowledge claims students produce, and the routes they take to generate those claims, are discussed in terms of the local, cultural practices of the community the student inhabits. In particular I focus on epistemic resources that philosophers have historically recognized as sources of knowledge: perception, introspection, memory, reasoning, and introspection (Chinn, Buckland, and Samarapungavan, 2011).

Finally, while math educators have drawn a clear distinction between procedural and conceptual knowledge (Hallett, Nunes, Bryant, & Thorpe, 2012)—which in broad strokes

distinguishes rote rule-following from comprehension of the meaning behind math actions—I use the term *understanding* to refer to students' capacities to enact the epistemic practices valued in their local community. If those epistemic practices focus on procedural math knowledge (e.g. following an action sequence to arrive at a normative math answer), then I define understanding based on students' knowledge of that sequence. In this way, I do not intend for understanding to refer to conceptual or generative knowledge of the meaning behind math procedures. Regardless of how we as researchers describe understanding, I follow what the math community at the field site considers to be math practices that student should know how to deploy.

1.7   Research questions

A decade-long lull in math attribution studies has motivated calls for more research (Shores & Smith, 2010), especially on how discourse in math settings shapes attributions of failure (Gunderson, Ramirez, Levine, & Beilock, 2012). This dissertation moves attribution research into the territory of the situated storytelling practices that accompany math tutoring, the space where negotiated attributions impact students' ongoing work. In addition, this dissertation challenges the assumption that ability, like aptitude, is stable and uncontrollable (Weiner, 1983), proposing instead that math knowledge operates as a situated, multidimensional skill (Abrahamson, Lee, Negrete, Gutiérrez, 2014; Enyedy, 2005). The following two research questions motivate the dissertation:

1. How do tutors and students jointly construct (co-narrate) stories about moments of failure during math tutoring sessions?

2. What epistemic resources merge together for elementary-school students to produce solutions to math problems? And how comprehensively do stories about failure account for the range of epistemic resources deployed in interaction?

1.8   Chapter summaries

The dissertation takes as one point of departure prior psychological research on attribution theory and epistemic cognition. In Chapter 2, I frame the dissertation as an attempt to see in social interaction what have traditionally worked as individualistic psychological theories (e.g. Hsu & Roth, 2012). In this literature review, I also start to explore the connections between how students and tutors co-operatively construct knowledge, how educators conceptualize math ability, and how students and tutors respond to obstacles to the knowledge-construction process. Finally, I situate the research project in the tradition of interaction analysis, outlining an approach to documenting patterns of social interaction in public acts of communication that stretch across the semiotic fields of talk, body, and environment.

Chapter 3 provides information on the data sources, participants, research design, and analytical tools that organize the dissertation. In brief, the project takes place at a non-profit, after-school learning center that serves low-income urban students, and focuses on 4th and 5th graders as they work on math homework with untrained adult volunteer tutors. Even though the data from this dissertation come from a larger design research project underway at the after-school center, I examine only data collected from students' baseline math homework practices prior to the intervention. The results emerge from fine-grained interaction analyses of seven tutoring sessions and from considerations of patterns that take place across these sessions.

Chapter 4 provides an introductory analysis of how two dyads handle the failure response process. This introduction to the analytical concepts and mode of analysis provides a rationale for the value of this research and orients the reader. In this chapter, I discuss how two student-tutor dyads co-construct stories about failure and how the choices they make in recognizing the

obstacle, attributing causes to the obstacle, and intervening to resolve the obstacle are mutually influential processes.

In Chapter 5, I present a detailed analysis of a broader sample in order to catalog the variation in the failure response process. I examine how seven dyads (including the two dyads from Chapter 4) handle the process of finding an obstacle, attributing causes to that obstacle, and attempting to resolve the obstacle. How these processes influence one another is a core theme of the chapter. Throughout the chapter, I ask questions about the how participants' choices in each aspect of the failure response process reflect specific learning goals, ideas about the capacities of students, and power dynamics.

Chapter 6 addresses the topic of epistemic cognition in a case study and considers how sources of knowledge—testimony, perception, reasoning, introspection, and memory—merge together, often simultaneously, over a short exchange between a tutor and student focused on correcting a math mistake. In describing how the student and tutor laminate multiple epistemic resources into an interpersonal trajectory that creates knowledge, I argue that math ability, or the ability to satisfy the epistemic ends of knowledge and understanding, is distributed across people and the environment. Obstacles to learning point to one or more of these resources failing on its own or in interaction with other resources and suggests that ability should not by default be understood as an internal, stable, and uncontrollable capacity.

In Chapter 7, I discuss the implications of this work for theories of failure, knowledge, and pedagogy. In particular, I argue that we should view math knowledge as the outcome of an activity that combines resources situated in multiple locations in a local ecology. The stories that students and tutors tell about moments that jeopardize valued epistemic ends become public vehicles through which students understand failure. Opportunities to modify failure response

practices in tutoring include giving students agency at different stages of the process, reflecting publicly and openly on the situated character of math knowledge, recognizing the difficulty of finding the etiology of student failures, and discussing how to handle the fact that the causal reasoning process organizes who in the community is expected to give time and effort to resolve the obstacle. Simply recognizing that attributions of failure find their way into everyday math discourse opens up possibilities for new studies on how to productively modify failure response practices to foster resilience and learning through failure.

Chapter 2
Prior research on failure, epistemology, and interaction

2.1   Literature review and theoretical framework

This literature review outlines four areas of research that serve as separate streams of influence on this dissertation: (1) Attribution theory; (2) Conversation/Interaction analysis; (3) Situated cognition; and (4) Epistemic cognition. The goal of this literature review is to provide an historical architecture and motivation for the study of how natural conversations and ideas about knowledge shape students' accounts of failure.

2.2   Attribution theory and interaction

Attribution theory is a conceptual framework that addresses how students and teachers' ideas about the causes of success and failure impact their own motivation (Kelly, 1973). The theory has historically addressed what some label phenomenological cognition, in that attributions are defined by what the individual *experiences when thinking him/herself* about the topics of success and failure. Graham (1991) articulates the phenomenological basis of attribution theory in her explanation that attribution judgments "depict the causal world as perceived by the actor" (p. 35).

Research in this tradition has suggested that more often than not, individuals explain success/failure as resulting from the causal ascriptions of ability, effort, strategy, task, and luck (Weiner, 2010). For example, a student may claim that he cannot solve a math problem because of bad luck, or more plausibly, because the problem was too difficult. After selecting a causal ascription, an individual may then construe the dimensions of each ascription as internal or

external to himself, stable or unstable, and controllable or uncontrollable. For example, task difficulty is understood to reside outside of the student, have the potential to vary over time, and exist beyond the control of the student.

As these dimensions line up (see Figure 2 below), the individual builds a model that makes a prediction about whether success will come in similar circumstances and how exactly to reach that success. The idea is that if one blames failure on a causal ascription believed to reside in the individual (such as capacity in working memory) and persist across contexts and time, even after concerted attempts at change, then subsequent failure will be anticipated and motivation will plummet. The selection of ascriptions and their associated dimensions can be driven by an immediate affect response (Weiner, 2010), beliefs about whether the potential for learning is fixed or malleable (Rattan, Good, & Dweck, 2012), and personal histories and social norms (Weiner, 2010), all of which combine to influence whether students respond to failure with a sense of helplessness or a desire to seek mastery (Dweck, 1975).

Outcome	Causal ascription	Causal dimension	Consequences
-Success -Failure	-Ability -Effort -Strategy	-Locus -Stability -Controllability	-Expect success? -What to work on? -Pride/shame?
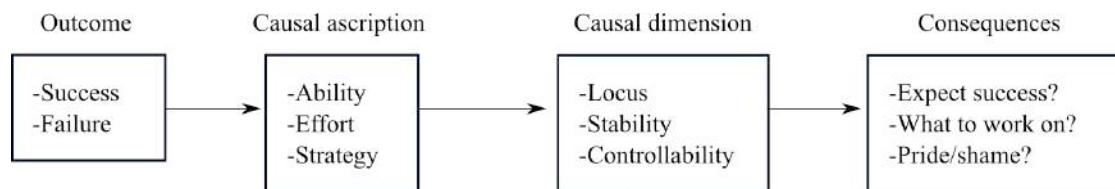
Figure 2: General model of attribution theory (adapted from Weiner, 2010).

For math students, thinking conscientiously about what generates math success and failure is important. A student floundering in math can blame lack of effort, inadequate ability, time constraints, divided attention, bad teaching, difficult math concepts, poor strategy, etc., and each cause would suggest a different approach to improvement and a different likelihood of success. Attribution theory suggests that the ultimate experience of motivation in mathematics occurs alongside a cascade of thoughts about *why* math difficulties are happening. In principle, this process should not be simple. The attempt to settle on an attribution of success/failure

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involves reflecting on how actions in the past generated the present outcome (Heider, 1958) provided a pool of potential actions that is *infinitely large* (Hesslow, 1988). Because there are often multiple causes of a single outcome and chains of causes extending back in time, this means that stories about the causes of failure can be more or less comprehensive and more or less geared toward informing effective interventions.

To add another layer of complexity, the process of formulating causal accounts of success and failure is less an individualistic pursuit than a collaborative effort (Gunderson, Ramirez, Levine, & Beilock, 2012). Because people make failure known to one another and reflect publicly on its causes and consequences, interpersonal interactions constitute one common way in which we understand the meaning of failure. How much power participants have to propose their own causes and design their own interventions, let alone determine what counts as failure, may be traceable as much to norms in the community as to individual psychological portraits. To provide contemporary context, a recent New York Times Magazine article (Pollack, 2013) suggests that many exceptionally successful undergraduate women in STEM credit academic struggle to lack of ability over inherent task difficulty. Professors and peers in the undergraduate community implicitly reinforce and even explicitly propose such ability-based attributions. If we take this observation to heart, this means that a central question for researchers and educators is how communities construct, propagate, and shape attributions during routine discourse.

At present, most attribution research entails subjects responding to forced-choice questionnaires and semi-structured interviews, separated in time and space from the causes and outcomes under scrutiny in the researchers' questions. Many such studies divide students and teachers into different experiments and ask for their reactions to hypothetical scenarios (Rattan, Good, & Dweck, 2012), further removing the attribution process from daily cultural activity.

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These classical experiments break down into three categories: situational (state) studies examine attributions made about hypothetical outcomes or past laboratory-based outcomes; dispositional (trait) studies ask participants to evaluate one-off statements about success/failure; critical incident studies ask participants to evaluate recent or long-past naturally-occurring outcomes in their lives (e.g. a grade on a school test) (Vispoel & Austin, 1995). In all cases, participants reflect on events that have come to completion. The result is that researchers have an excellent understanding of correlations between professed, post hoc attributions and academic outcomes, yet a limited understanding of enacted attributions, or how teachers and students collaboratively negotiate the selection of attributions during the course of math activity. Simply put, the interpersonal dynamics of attribution theory are poorly understood (Weiner, 2000).

Provided this gap in the literature, why would it matter to study the interactional constitution of attributions? In adopting a situated lens on human participation and learning, it is recognized that activities first occur between people and in the act of communication before an individual transforms that activity into an internally available resource (John-Steiner & Mahn, 1996; Vygotsky, 1978). In this way, we would expect that how attributions surface in conversation during collaborative attempts to understand failure would shape how an individual comes to think about his/her own outcomes in math. In developing a better understanding of attributions in discourse, we can inform teachers and students about how to better intervene during interaction to foster more productive attributions. In their recent review of gender-related math attitudes, Gunderson et al. (2012) support this position, arguing that research should "further elucidate the mechanisms of math attitude transmission [which] can provide a framework for evaluating existing interventions and developing powerful new interventions for parents and teachers" (p. 162). In addition, the standard dimensions of causal ascriptions—locus,

stability, and controllability—may take on new meaning in the context of interaction. When construed interactionally, the causal ascription of ability could involve both internal and external dimensions, dependent on the existing skills of the student, the potential of the teacher to draw out and develop those skills, and the availability of external tools. Re-assessments of the dimensions of ascriptions could productively influence students' motivation to pursue mathematics.

In education, a select few studies have broached the subject of attribution construction in interaction. In a laboratory study, Graham (1985) shows that teachers' displays of pity or anger in reaction to students' failed attempts to solve a puzzle result in the students attributing the failure to low ability and low effort, respectively. Graham's (1985) study moves in the direction of an interactive account of attribution construction, but for important experimental reasons, confines interaction to the one-way flow of a single utterance from speaker to hearer. The more complex and open-ended environment of parent-teacher math conferences is representative of how discourse gives shape to attribution construction in math education (de Haan & Wissink, 2012). In their study, Haan and Wissink (2012) find that math teachers mostly dominate the process of assigning attributions (e.g. in suggesting that lack of effort is responsible for minority students' failures) but that the attribution process occurs in chain-like sequences, such that past attributions from one conversation partner signify the attribution focus taken by another partner. In moving away from the tradition of studying individual phenomenological judgments about success/failure, these research efforts begin to orient within the tradition of discursive psychology (Hsu & Roth, 2012), which assesses how people in interaction jointly and publicly construct understanding within *intact activity systems* (Greeno & MSMTAPG, 1998). In the subsequent section, I further examine attempts to study attribution theory in discourse

environments and formulate a broader model for how reasoning about the causes of failure manifests in interaction.

2.3 Storytelling as causal reasoning

An entry into discourse surrounding math attributions would help educators understand how conversations mold attributions, and ultimately, help students locate and interpret productive attributions during math activity. The frameworks of conversation analysis (CA) and interaction analysis (IA) offer excellent starting points for this program of research. In both frameworks, the goal for researchers is to describe how conversation participants accomplish communication in action (Schegloff, 1972). Analysts work to characterize the interrelationship between aspects of discourse visible to an observer but managed by the participants. For example, how participants take turns in conversation (Sacks, 1992), phrase requests in different contexts (Brown & Levinson, 1987), or operate their hands to register more precisely the location of an event (Streeck, 2009), are all examples of how interactants manage the task of communication. While CA traditionally focuses on interactions in the verbal channel—intonation, prolongation of words, silences, overlapping talk, and pitch contours—IA broadens the channel to include interactions between people, their bodies, physical materials, and the environment (Goodwin, 1994, 2013; Jordan & Henderson, 1995). These methods can be used to recognize how cognitive and psychological processes are shaped through mundane social interaction, an approach others have termed cognitive ethnographies (e.g. Williams, 2006).

For the purpose of this program of research, it is relevant to begin with the observation that participants in interaction often discuss and enact ideas about causal reasoning—creating a social context in which stories about failure are turned over again and again. In Bruner's (1991)

terms: "One of the principal ways in which we work "mentally" in common, I would want to argue, is by the process of joint narrative accrual" (p. 20). Causal reasoning is at the heart of attempts between math teachers and students to make sense of what has gone wrong and what could be done to improve performance during a math lesson. To put it briefly, students and teachers formulate thoughts about which present events are *causing* someone to jeopardize their goals, which past events *caused* that present obstacle, and which new actions might *cause* success, in effect building a causal chain of events that traces the origins of failure to the possibility of success. Interactions provide opportunities to probe and reflect on which past events lead to desirable outcomes and what should be done with that knowledge going forward (Turnbull & Slugoski, 1988). Indeed, these causal models can pertain to a wide range of circumstances, such as why dark clouds signal the chance of rain or why it is difficult to stand up on a surfboard. Interactions provide spaces in which causal attributions of success and failure can be floated, negotiated, and resolved.

In conversation analysis, researchers have studied how stories, even relaxed ones shared around the family dinner table, focus not only on past moments of significance but also on the causes of those moments and their projected consequences (Ochs, Taylor, Rudolph, & Smith, 1992). For example, Ochs et al. (1992) analyze an interpersonal situation in which a child recalls a memory of accidentally ingesting a hot pepper. As the story unfolds at the dinner table, the family searches for accounts to explain why the pepper was ingested (Mom mistook the pepper for a green bean), who deserves the blame (Mom, for giving the pepper to a two year old), what resulted from the main event (the child's mouth burning), how the community reacted to the event in the past (with laughter or with enjoyment), and what reparations to presently seek (the child pinches his mother's cheek at the dinner table). That is, stories build theories of causal

relations: What happened, why did it happen, what was the result, and what should be done now? In this way, stories about success and failure become conversation vehicles for thoughts about attributions, organizing how interactants share their reflections on why an outcome transpired and what it means for subsequent action.

More broadly, human cognition excels at patterning events in narrative form (Bruner, 1991; Herman, 2009). In highlighting that one of the functions of stories is to link the past with the present, Bruner (1991) articulates how stories uncover deviations from the norm: "The perpetual construction and reconstruction of the past provide precisely the forms of canonicity that permit us to recognize when a breach has occurred and how it might be" (p. 20). Even in situations in which people are not telling a story, cognition can be understood to organize action in narrative terms, outlining a causal chain that predicts how past/present events will impact subsequent events (Grodal, 2003). An alternative narrative model to Ochs et al. (1992) is that an agent assembles resources into a strategy to overcome an obstacle toward a goal (Steen, 2005). In the context of math failure, for example, a student (the *agent*) might blame the fact that he left his textbook at home (a lack of a *resource*) for his struggle to solve a math problem (the *obstacle*) and finish homework (the *goal*). The student might solicit help (the *strategy*) from a math tutor (a new *resource*) to overcome that obstacle. Consequently, during math activity, students and teachers' thoughts about causes of success/failure would take shape within the context of a story-structured interaction.

Looking across these frameworks, we can describe stories as mechanisms through which conversation participants talk about the causes and consequences of failure, in addition to the resolutions/strategies that could guide reparations and stoke progress toward valued goals. Importantly, social interactions around failure manifest less as one-way transmissions than as

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territories for negotiation. Around the family dinner table, parents and children collaboratively construct multiple versions of what purportedly happened in reality, challenge alternative explanations, posit causes that serve personal interests, and inspect the methods by which other contributors arrive at conclusions (Ochs et al., 1992). These findings beg the question of how math communities, in adherence to their local power structures, social norms, and knowledge about mathematics, similarly approach the territory of communicating the causes of math success/failure during moment-to-moment classroom activity.

The social treatment of failure is not necessarily equivalent to how individuals would privately think about failure. This is not to say that social interaction around failure cannot influence private cognition about failure, but that as a start, we can expect that social contexts provide specific constraints on discussions about failure. In a recent instantiation of this discourse approach, sports psychologists study athletes' attributions in the flow of talk, documenting how local conversation dynamics influence athletes' breakdowns of past successes and failures (Finlay & Faulkner, 2003; Miller, 2012). To give a few examples, athletes suppress their positive self-assessments to avoid the appearance of gloating; flip-flop between attributions focused on the dreadful play of the other team, their own team's skill, and sheer luck; and hedge claims to save the face of others (Finlay & Faulkner, 2003). Rather than seeking an unvarnished reflection of athletes' private attributions of success and failure through question and answer protocols, this research explores how features of discourse, such as the presence of an audience or the reason for providing an attribution, provide contours through which attributions are given specific shape in interaction. Turnbull and Slugoski (1988) anticipated this discursive turn when they argued that for attribution research, "the proper unit of analysis is the question-answer pair, or, to put it another way, the puzzle-resolution pair" (p. 67). Once situated in discourse, the

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process of attribution selection can be understood to take influence from numerous factors, such as question phrasing, tone of voice, the knowledge states of the participants, what is taken for granted versus what is considered abnormal, the problems participants care to solve, and conversation maxims such as being clear, relevant, truthful, and informative (Turnbull & Slugoski, 1988).

In reflecting on tutor-student interactions, one might question how often tutors or students actually launch into a story. This hesitation opens up for an important distinction about storytelling versus story constructing/enacting. The vast majority of research on narrative focuses on those captured in stable media, such as print or film, and those told in conversation about the past or future in which a speaker starts and completes the telling of the story (Herman, 2009). Conversation analysis researchers broaden this window slightly to include how participants set up spaces in conversation that forecast where they are headed, allowing the speaker enough turns-in-talk to tell the story from inception to completion (Sidnell, 2009). However, both approaches elide the common occurrence of narrative in routine action. Grodal (2003) notes:

> Such descriptions have some advantages, but also problematic consequences, because phenomena such as "story" or "narrative" are then only defined in relation to their media realizations, not by their relation to unmediated real-life experiences and those mental structures that support such experiences" (p. 129).

This broader view posits that cognition structures experience in narrative terms—even when we are not explicitly telling a story to a third party. When people walk into a grocery store or prepare a meal, a background narrative motivates their moment-to-moment actions and decisions (Grodal, 2003). This observation suggests a close connection between goals and actions (Lave, 1988). In this way, we not only tell stories retrospectively and prospectively, we live them in the

present, in our routine actions and interactions with each other and the environment. To draw an analogy to film, Damasio (1999) notes that, "Movies are the closest external representation of the prevailing storytelling that goes on in our minds" (p. 188). Math tutoring sessions, accordingly, involve co-occurring talk and action that over time construct interactions that fit the classic narrative paradigm: What are participants doing, what are their goals, what resources do they have, what obstacles are they facing, and what strategies do they use to overcome those obstacles (Steen, 2005)? In claiming that participants co-construct stories, the intent here is to highlight that interactions in math tutoring sessions *can be studied from the perspective of narrative structure,* regardless of whether the participants themselves believe they are telling a story. Goal-directed social interactions have story structure, but they are not always occasions in which participants set out to tell the story. This re-framing validates lived or enacted narrative patterns in the present.

2.4   Summary of attributions in story-structured interactions

The framework detailed thus far warrants novel approaches to the study of how the attribution process takes shape in math learning environments. The exploration of whether attribution selection evolves over time to establish new conditions for learning could be studied as an interactional achievement. These interactions can be documented beyond the verbal channel of CA to account for body language, gesture, eye gaze, and material resources (elaborated in the following section), all features recognized as essential to the ecology of communication in the IA framework (Goodwin, 2013; Jordan & Henderson, 1995). This approach honors and reflects critically on the everyday practices of students and teachers in the classroom (Erickson, 2011).

2.5   Revisiting ability in light of situated cognition

Thus far, I have positioned the process of judging causes of success/failure within the story-structured interactions of teachers and students in math environments. A second contribution of this dissertation involves considering how situated cognition recasts the causal ascription of ability/skill and the causal dimensions of locus, stability, and controllability. The goal is not to test the veracity of situated cognition per se, but to explore how the situated framework gives new meaning to and makes new predictions within attribution theory.

Discussions about success/failure entail conjectures about ability. Maybe somewhat surprisingly, however, many consider ability to be a persistent and uncontrollable trait, even for children as young as eight years of age (Stipek & Gralinski, 1991). In attribution theory, some researchers treat ability and skill interchangeably (Covington & Omelich, 1979), making it impossible to distinguish respondents' differences in opinion about the two constructs, and most other research assumes at face value that ability is stable and uncontrollable (Barker & Graham, 1987; Graham & Barker, 1990). However, Weiner (1983), upon whose theory attribution research builds, has been forthcoming about the prospect that thoughts about ability vary between people and across situations. That is, Weiner (1983) notes "the importance of assessing the subject's perception of the stability of the causes under consideration rather than merely assuming, for example, that ability is stable" (p. 537). In a wry critique, Russell (1982) describes the tendency to assign default meaning to attributions as, "fundamental attribution researcher error" (p. 1137). Even more importantly, regardless of prior beliefs, teachers can learn to view academic potential as unstable and controllable, productively impacting their attributions and projections of success (Rattan, Good, & Dweck, 2011).

Combined with interventions focused on effort, these findings point toward a pedagogical goal: Encourage students to see effort as responsible for success, ability as potentially controllable, and learning as incremental (Dweck, 2007). Nonetheless, students who believe that learning is attainable through hard work must still decide how and where to target their effort, a question central to attribution theory. Self-efficacy and a sense of personal responsibility come from believing that learning is incremental but also from knowing how to control desirable outcomes (Graham, 1995). Learning communities could confront the notion that "not all effort is created equal" (Gomez, 2013, personal communication). In this dissertation, I do not aim to prove that some grit is more productive than others, but I couch my analysis in the form of a call to consider this possibility.

One way that I argue that productive grit could be achieved is by educators and students prying open the black box of ability, assessing both weaknesses and strengths (Rattan, Good, & Dweck, 2011) and formulating exactly where effort would be maximally directed. Instead of ignoring ability and focusing only on effort, educators in conversation with students could reflect openly on ability to find more precise causes of math success and failure. The search for fine-grained causes, if built upon an awareness that ability results from multiple skills, could provide students with an actionable roadmap for channeling effort. With this long-term vision in mind, I turn to how we can construe mathematics ability according to situated cognition, and in turn, consider how stories about *lack* of ability could become more comprehensive, equitable, and effective in guiding productive interventions.

2.6   The notion of ability in situated cognition

The success of this approach hinges on re-framing the concept of ability. If ability were to remain understood as stable and uncontrollable, then learning communities would have little

reason to search for ways students could improve. If ability can be framed as unstable/situational and controllable—more of an unrealized potential than something manifest in the here and now—then learning communities would have clear warrant to reflect carefully on students' skills and their potential for change. The approach taken here is to conceptualize ability in the way situated cognition researchers describe knowing and skill. Instead of thinking of ability as an internal and fixed trait, situated cognition construes the capacity to generate knowledge as the result of *lamination* (Goodwin, 2013) between multiple aspects of an activity. Accordingly, knowing draws on interactions between multiple sources of knowledge (Chinn, Buckland, & Samarapungavan, 2011) and ability can be measured by how well students draw on and integrate each source.

On what basis should we discuss conceptions of ability in the same breath as conceptions of epistemology, or the nature of knowledge and knowing (Hofer & Pintrich, 2002)? Indeed, if a student has the *ability* to know an answer in mathematics, this means that the student can enact the "routes to cognitive accomplishments" (Solomon, 2007, p. 413) that constitute knowledge in that community. Claims about whether students are *able* to know something involve what the *knowing process* entails. To give an example, if mathematics knowledge derives solely from memorization, then ability can be determined by how well students memorize, but if mathematics knowledge derives from memorization and creative thinking, then ability must be determined taking into account both factors. In short, how we describe the structure of knowledge in mathematics in part determines whether we believe students will have the ability to know mathematics. This section examines how situated cognition describes knowing—defined here as the process by which communities come to understand relevant features of their worlds— and considers the implications of this re-framing for attribution theory.

Let us begin with an example in the context of archaeology. The classic view that ability is stable, internal, and unchangeable would mean that a newcomer to archeology who struggles, for example, to properly classify soil samples would be unable to become an archaeologist. The ability to classify soil would be missing from the newcomer, and that lack of ability would continue forward in stable fashion even when confronted with attempts of the student and community to improve that ability. In contrast, if we look at the situated character of the setting in which archaeologists classify soil, a different picture emerges. For a newcomer to archaeology to know how to classify the color of soil according to the criteria and the goals of her research community, the process involves having access to a physical Munsell color chart, hovering the Munsell chart over soil, allowing for the sun to strike the Munsell chart under full light, placing the body (and eyes) of an expert and novice over the chart, reasoning about the similarities in color between the soil and the colored emblems on the chart, marking a code in field notes, and talking and gesturing constantly throughout this scene (Goodwin, 1994).

In light of this situated description of knowing, the concept of ability involves more than just an archaeologist's internal skill. The novice archaeologist must also have access to an *external* tool (the Munsell chart), an *external* environment (sun), and an *external* individual (an expert geologist), not to mention *internal* capacities involved in perceiving the space and handling tools, in order to successfully recognize the color of a soil sample. Whether the newcomer's ability is stable and controllable would depend on the availability of this suite of overlapping features (sun, Munsell tool, experts, malleable bodies) and whether the practices and goals for the archaeology community change over time. Knowledge that the community considers accurate and relevant emerges from a configuration of resources assembled into a

specific trajectory; lack of ability in a newcomer, in turn, marks a breakdown in that configuration, but does not exclusively implicate permanent flaws in resources in the student.

Consequently, situated accounts of knowing challenge the classic formulation in attribution theory that ability can be cast solely as an internal, stable, and uncontrollable trait. Heider (1958), whose research inspired attribution theory (see Weiner, 2010), formulated an account of causes considered to reside inside the person and those that reside outside the person: "In common-sense psychology (as in scientific psychology) the result of an action is felt to depend on two sets of conditions, namely, factors within the person and factors within the environment" (p. 82). Situated cognition breaks this clean boundary and formulates an account of knowing and ability that stretches across both spaces. Lave (1988) explains: "'Cognition' observed in everyday practice is distributed—stretched over, not divided among—mind, body, activity and culturally organized settings (which include other actors)" (p. 1). The ability of an archaeologist, for this reason, hinges on both internal skills and a complex of external resources.

For now, let us take a step back and examine the background assumptions that underwrite the situated framework. Researchers in the situated tradition emphasize activity (Dewey, 1931; Wertsch, 1981), historical context (Cole & Engestrom, 1993; Saxe, 1999), communities as units of analysis (Hutchins, 1995), recursion between people and settings (Keller & Keller, 1993; Lave, 1988), and the genetic methodology that emphasizes change over time (Vygotsky, 1978). This means that situated researchers study people pursuing goals within the settings that traditionally house their activity (Freire, 1970)—studying a blacksmith in his lab (Keller & Keller, 1993), shoppers as they use mathematics in a grocery store (Lave, 1988), or children as they negotiate the meaning of maps in classroom discourse (Enyedy, 2005). In many cases, the history of those communities, whether manifested in tools or social norms, is understood to

frame the present activity, which results in an expansion of the unit of analysis beyond the focal research subject. As participants manipulate their environments, the environment can in turn discipline their activity, resulting in a recursive relationship between the actors and their setting (DeLiema, Lee, Danish, Enyedy, & Brown, in press).

Situated theory reworks many of the ontological assumptions bound to behaviorist, constructivist, and classical cognitivist perspectives. For example, situated cognition rejects the separation of mind from body, person from environment, person from tools, and person from social others. What it means to *be* according to situated cognition is to *be bound* to the settings in which people develop and learn, rather than to be a separate decision making system relying on mental symbols "protected from the external world" (Newell, Rosenbloom & Laird, 1989, p. 107). Instead of viewing cognition as the process of connecting abstract symbols exclusively in the head, situated cognition views thinking as extending out into the environment. For example, instead of rotating Tetris blocks in working memory, game players quickly press buttons to rotate the blocks on screen, a strategy that saves cognitive energy (Kirsh & Maglio, 1994). To give another example, geologists integrating observations from outcrops move models aside, place some side by side, and physically rotate models, all in the service of using the external environment to alleviate internal demands on spatial reasoning and memory (Kastens, 2008).

To provide historical context, Hutchins (1995) explains that what got "lost in this move" (p. 361) to classical, internal cognitive science is the sociocultural system in which there is a "mathematician…interacting with the material world" (p. 363). The mathematician who wrote digits on paper (which stored the digits), and then visually inspected those digits (with perception), before performing a next calculation became flattened into a chain of symbolic events. Symbolic chains work for computers, and naturally extend the math capacity of humans,

but they do not represent how humans think through mathematics. Math is rooted in embodied interactions with the local tools available culturally and historically to construct understanding (Saxe, 1999) and knowing occurs through cultural mediation (Cole & Engestrom, 1993; Vygotsky, 1978).

Situated cognition recognizes that knowing comes from a synthesis of resources, including physical and conceptual tools (Lave, 1988; Vygotsky, 1978), moment-to-moment perceptions (Clark & Chalmers, 1998), embodied resources (Streeck, 2009), and social interactions (Chinn, Buckland, & Samarapungavan, 2011), amounting to what we might call an *epistemic ecology* or *landscape of knowledge* (Goodwin, 2013). Epistemic ecologies refer to the successive lamination and transformation of bodies, material artifacts, the environment, perceptions, and talk, as interactants collaborate to mutually transform resources into ways of knowing. When a student is "able" to know something, it is because he/she has laminated multiple semiotic resources into an activity situated in a socio-historical setting.

2.7   Sources of knowledge in situated cognition

Building on the epistemology literature in philosophy, Chinn et al. (2011) make a case about sources of knowledge that is consonant with situated cognition:

> A physics student's knowledge of topics such as forces and friction rests jointly on the sources of his or her perceptual experiences, the testimony of teachers and scientists, reasoning about course readings and experiences, and memory needed to retain all these past knowledge-acquisition episodes (Chinn et al., 2011, p. 153).

In short, educational researchers could consider the prospect that multiple sources of knowledge interact to create opportunities for knowing. For our purposes, an exploration into interaction

fundamentally reshapes the question of what counts as knowing. It becomes evident that many mundane events or actions make their way through and from a community of interactants in the process of becoming a source of knowledge. Direct perception of the world, ideas from other people, recollections from memory, simulations run in the imagination, and reflection on our own cognitive experience can merge together to help people achieve epistemic aims, such as creating knowledge or fostering understanding.

In summary, instead of thinking of math failure as an indicator of wholesale inability, we can consider how embodied tools (gaze, gesture), physical tools (paper, pencils), memories (math procedures), and social others (teachers, peers) interact within an epistemic ecology to create the conditions for knowing. The ability to know becomes a product of the distributed local ecology comprised of individual cognition, social interaction, and physical materials. If knowledge derives from interactions between so many dimensions of an epistemic ecology, then the notion of being "able" to know something could be pried apart and dissected more conscientiously in learning communities. Even though the causal ascription of effort remains important (e.g. Graham, 1991), uncovering how to achieve productive effort must to some extent entail reflection on how we achieve knowledge and how that knowledge-construction process can vary. A distributed take on knowledge would still recognize uncontrollable causal ascriptions (e.g. not having paper to compute math calculations in a grocery store or not having a Munsell chart at a geology field site), but this perspective accounts more comprehensively for interactions between multiple causes, considers factors beyond individual skill, and opens up possibilities for different types of interventions.

How different is this conceptualization of ability/skill/strategy from the way attribution researchers have dealt with these concepts? In the first place, Weiner (1985) notes that effort and

ability are the dominant causal ascriptions in achievement contexts, with task difficulty and luck also pertinent for participants in post-hoc reflections. However, others have found that the factors of interest, roles of others, and strategy are also relevant causal ascriptions in achievement contexts (Vispoel & Austin, 1995). In short, most attribution research does not examine skill/strategy beyond the construct of ability versus effort. Those studies that do discuss finer-grained thoughts about ability have defined strategy as (1) the use of cognitive strategies in which people rehearse plans, monitor their success, and summarize/paraphrase (Shores & Shannon, 2007); (2) the use of mathematical procedures, such as how to apply a division algorithm (Schunk & Gunn, 1986); and (3) whether the student "used the right/wrong study or practice methods" (Vispoel & Austin, 1995, p. 385). In all cases, researchers define strategy as a construct orthogonal to ability and refer to strategy in the limited sense of internal practices. The present project aims to re-describe ability as the strategic use of multiple sources of knowledge.

2.7 Connecting attribution theory, epistemology, and storytelling

In summary, this dissertation brings together students' abilities to construct knowledge and social practices surrounding failure, exploring a relationship between local/practical epistemologies (Hogan, 2000; Sandoval, 2005) and attributions that researchers have only just started to unfold. For example, Kienhues and Bromme (2011) examine how individuals (1) reason about Internet articles that discuss cholesterol risk and (2) consider their own ability to assess science claims. In properly evaluating conflicting information about cholesterol, individuals have to weigh two factors, how much expertise they personally have in judging the scientific findings and the quality of the science knowledge itself. Participants' interactions with the text thus demand the coordination between thoughts about one's own science skill and

thoughts about the knowledge posited in the text. We can phrase this relationship as one of coordinating achievement orientation (or beliefs about what one's current ability level can accomplish) and the demands of the knowledge task (Licht & Dweck, 1984). Kienhues and Bromme (2011) frame this relationship as critical to the next generation of research on epistemic cognition, proposing "that an empirical investigation of the interplay between beliefs about abilities and epistemic beliefs can contribute to the ongoing debate on the conceptualization of epistemic beliefs" (Kienhues & Bromme, 2011). This question is central not only to researchers' conceptualizations of epistemology, but also to educators' goals of teaching students to think productively about both dimensions and to realize change in both over time.

In connecting attributions of success/failure to epistemic cognition, it is worth considering the extent to which epistemic cognition is stable for individuals. In the field of science education, what teachers claim to believe about science knowledge does not always match how they interact with science knowledge in classroom situations (Tobin & McRobbie, 1997). Moreover, even professed epistemologies gauged in different contexts do not cohere into consistent belief systems (Buehl, 2008; Leach, Millar, Ryder, & Sere, 2000; Roth & Roychoudhury, 1994). Furthermore, enacted epistemologies vary over the course of single activities (diSessa, Elby, & Hammer, 2002; Louca et al., 2004; Rosenberg et al., 2006). What is clear is that individuals' professed thoughts about what counts as knowledge lag far behind the multifaceted epistemic actions they routinely enact (Hammer & Elby, 2002). However, given that students' ideas about knowledge are flexible, numerous, and situation-specific (Louca, Elby, Hammer, & Kagey, 2004), educators could begin to consider how changes to the resources students recruit for thinking about knowledge could change how they assess their own learning potentials. In summary, this dissertation explores two angles on attribution theory, how teachers

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and students co-construct stories about failure and how educational researchers can re-consider the notion of ability as a situated, multi-part knowledge construction process.

Chapter 3
Method

This dissertation presents a qualitative analysis of students and tutors' conversations during moments of struggle on math homework, in addition to an analysis of the situated resources students recruit to construct mathematics knowledge valued in the school community. The data are part of a larger design research intervention at the research site (details to follow), but the present study focuses on moments of interaction uninvolved with the intervention.

3.1   Setting

The setting for the project is a STEM non-profit after-school center that accommodates 3rd grade through 8th grade students mostly from underserved Spanish-speaking families who live in low-income urban communities. Tutors in the program are volunteers from local colleges and local businesses. At the time of the study, the after school program had served its community for three years, running every weekday from 230pm-630pm. 80 students were enrolled in the program throughout this study. The long-term goal of the non-profit was to increase STEM participation in underrepresented communities at both the collegiate level and in the workplace. The stated values of the after-school community (posted on walls at the center and integrated in its tutoring manual) were to help students see learning and success as possible through *curiosity, grit, gratitude, innovation, collaboration,* and a sense of *possibility.* Each afternoon, students began by working on their homework (including non-STEM topics) at a table with four other students and anywhere from one to two tutors. After finishing homework, students were allowed to work on STEM enrichment activities (e.g. math puzzles, Kahn Academy exercises, math flash cards)

and have free play in a recreation room before working on a collaborative STEM project (e.g. building and testing bridges fashioned from dry spaghetti, programming computers).

At the time this project started, the after-school learning center had already formulated explicit guidelines relevant to attribution theory. The director of the program commonly reminded tutors that they should never tell students that they were bad at math or that they could not succeed in math. Furthermore, tutors were encouraged to talk to students explicitly about effort, to praise effort, and to help students see that effort begets success. In terms of the discourse environment, tutors were asked to help students less through giving answers than asking questions. In addition, as stated in the program's tutor guide, tutors were asked to "keep things positive" and to consider themselves GPS-like guides to developing math practices.

At least two epistemic aims/ends (Chinn, Buckland, & Samarapungavan, 2011) were central in structuring math-tutoring sessions at the after-school program. The first epistemic end—which I call knowledge—involved students and tutors aiming to generate correct answers on homework math problems. If students did not have the correct answers on their assignment, barring unusual circumstances, they would be expected to look back over their work and make revisions (to achieve the normative math solution) before moving on to other activities. The other epistemic end—which I call understanding—involved an expectation that students would know how to independently enact a route toward the correct answer. These routes often meant following procedures, but students were nonetheless expected to understand how to deploy those procedures. Staff at the learning center consistently reminded tutors at the start of an afternoon session to ensure that students did the bulk of the work and to help students move toward independence in conducting that work.

3.2   Participant selection

In the text, I refer to each student and tutor with a unique letter unrelated to participants' actual names (e.g. J, Z, F). To signal whether that letter refers to a student or tutor, I include a preliminary letter S for all students (e.g. SJ, SZ, SF) and a preliminary letter T for all tutors (e.g. TC, TM, TD). Student participants were drawn from 4th and 5th grade. One of the students (SZ) was in 4th grade and five of the students (SJ, SF (and SF2), SD, SG, and SU) were in 5th grade. Four of the participants (SZ, SF (and SF2), SJ, and SD) were enrolled in an urban title 1 public school and two of the participants (SG and SU) were on scholarship at a private, urban religious school. Five of the students were native Spanish speakers (SZ, SF (and SF2), SJ, SD, and SG) and one was a native Hindi speaker.

I selected students from these grades because it is during these critical years of late elementary school that students' attitudes toward math begin to change, typically in a negative direction (Gunderson et al., 2012). As the after-school program served more than 80 students at the time of the project, student participants were selected based first on their own and their parents' consent to participate in the study and second on how much they were struggling in mathematics. With respect to the latter assessment about math knowledge, I based this decision on conversations with the administrators and tutors of the program and on assessments of the quality of students' work on independent enrichment activities provided by the program (such as measures of speed at solving double-digit multiplication problems). These selection decisions bias the study in the direction of students who were already struggling to complete their math homework. Even though studies of failure among high-achieving students would productively shape pedagogical theory, I chose to begin this program of research focusing on students most in need. These are students who routinely experience failure on their homework.

Originally, 10 students (5 female) and 10 tutors were selected to participate in the study. Parents, students, and tutors all consented to participate in the study according to IRB-approved guidelines. Two student participants came to the program with their math homework finished every day of the study, and so could not provide any relevant data. Another participant became significantly distracted by the presence of the camera on the first and second recorded sessions. Together with the staff at the after-school program, I decided that we could not justify continuing on with him as a participant. This left the pool of students that I described above.

All but one of the tutors selected to participate in the study had minimal formal training in teaching. Two of the tutors (TM & TF) were undergraduates majoring in STEM, one tutor (TO) had just started a masters program in education, two of the tutors (TN and TK) worked professionally in STEM careers and/or were pursuing higher education degrees in STEM, and one tutor (TC) worked in a non-STEM field. Four of the tutors (TM, TF, TN, and TC) spoke Spanish as their native language and two tutors spoke English as their native language. Because all but one of the tutors had received formal training in education, this study represents a pool of individuals interested in pedagogy, motivated to volunteer time to support academically struggling students, and positioned in the nascent stages of developing a teaching practice. All of the tutors had already volunteered on a weekly basis at the program for at least four months prior to the start of the study.

3.3   Research design

This study recruits the analytical approach of interaction analysis, which involves fine-grained descriptions of the discourse patterns of tutor-student dyads. The method traditionally involves recording participants as they engage in practices that would take place even without the presence of the researcher. As such, I studied tutors working with students on homework that the

students brought to the after-school program and needed to complete for school. I filmed each dyad on five to ten occasions for the duration of the time the student and tutor spent working on math tasks during that day's homework session. Students spent anywhere from a few minutes to over an hour working on their math homework. The tutor who worked with the focal student on a given afternoon was also responsible for helping two or three other students seated at their table (who were not participating in the study).

The director of the program typically decided where students would sit and with which tutors, and I tried to interfere as least as possible with that selection process. This meant that the dyads we had pre-selected often did not match up together, whether because of tutor or student absences or because of other demands at the after-school program. It would have been a major disruption to the program to keep the same tutor-student dyads together throughout the study. For the purpose of the present study, however, because I am focusing on only one exchange per dyad, this issue is less relevant.

I collected audiovisual recordings that captured participants' faces and bodies, and to the extent possible, the artifacts with which they interacted. I intended to use two cameras per dyad (as in Brown, 2009), but was limited in camera resources and could not follow through with that plan. Instead, I used a small, high-definition GoPro camera raised slightly above the table (on books or trays) pointed at the participants. For each session, I placed the camera in the proper location, greeted the student and tutor, pressed record, and then walked away. I asked the tutors to click the "stop recording" button when they finished math homework, and the students quickly caught on to that practice. I remained at the after-school program tutoring students at other tables.

There were two additional aspects to the research design that will not be discussed in the analysis part of this dissertation. First, I conducted interviews after each tutoring session, gauging students' explicit ideas about attributions of failure and epistemic practices. Because the present study is focused on enacted epistemic and failure practices, I will not be involving this post-hoc interview data in the analysis. Second, after the initial baseline period in which I filmed participants' existing practices (~3 sessions), I worked with 7 students and tutors to conduct a modest design research intervention, organized according to the principles of *conjecture mapping* (Sandoval, 2013). Tutors and students were asked to orient toward the goal of understanding what leads to math knowledge, attend to how effort supports learning, expect that both parties would collaborate in the failure inquiry process, and playfully explore what happened when some knowledge resources were removed from the setting. Data from the design-research intervention will also not be discussed in this dissertation.

3.4 Analysis

The analysis addresses how the tutors and students create stories about causes of failure and recruit (and build into their stories about failure) epistemic resources to achieve valued epistemic ends (knowledge and understanding) during math homework. In broad strokes, I conduct a fine-grained interaction analysis of the multimodal resources on which participants draw and the moment-to-moment interactions they deploy in their epistemic cognition and attribution judgments. The analysis focuses on seven dyads. I arrived at the point where I selected these seven conversations in the following way: (1) For each dyad, I found two or three obstacles that the tutor and student publicly discussed; (2) I transcribed these exchanges and began comparing them; (3) I gravitated both toward quick failure responses and also more drawn-out failure responses; (4) I started reaching a point of saturation in which I noticed common structures

across the exchanges; (5) I selected one exchange per dyad (seven in total) to capture the diversity of failure response processes. I provide more detail about this selection process throughout this methods section.

The analysis involved a back and forth between relevant theoretical frameworks and constant comparative analyses of the data for the project. I began with three episodes, attempted to apply and discover categories, and then iteratively expanded the analysis to an increasingly broader sample of about 20 moments of interaction, refining the categories as needed (Glaser & Strauss, 1967). As conceptual categories emerged out of the data, based on both past research and new discoveries, I transcribed subsets of the material, wrote memos documenting their construction and interrelations, explored categories in video analysis sessions with a local research group, and reified and revised the categories upon further analysis. This approach enacts the constant comparative method (Glaser, 1965) and many principles central to interaction analysis (Jordan & Henderson, 1995). In summary, I wrote memos to organize my thinking, drew flow charts, and iteratively defined constructs, all the while returning on a daily basis to the video data—watching and re-watching moments of interaction—as a way to keep my inferences about common structures of the failure response process grounded in the data.

Throughout this analysis period, I also frequently thought about and returned to readings on frameworks central to attribution theory, narrative, and epistemic cognition. I considered the narrative theories of Ochs et al. (1992), Steen (2005), and Grodal (2003) throughout the analysis, specifically thinking about initiating events (a central problematic event or circumstance, such as struggling on a math problem), the relevant past, present, and future moments that surround the initiating event, ways of dealing with the event, and consequences (Ochs et al., 1992). I also considered how co-narrators depicted their goals, resources, obstacles, and strategies (Steen,

2005). With respect to the construct of attributions, I kept in mind the theoretical framework of attribution theory (Weiner, 1983; Grahanm, 1991) and successful attempts to port attribution concepts into discourse environments (Finlay & Faulkner, 2003; Haan & Wissink, 2012; Miller, 2012; Vliet, 2009). I focused on the causal ascriptions that tutor-student dyads naturally discussed (e.g. ability, effort, skill) and considered whether these causal ascriptions were constructed as internal/external (locus), fixed/variable (stability), and controllable/uncontrollable (controllability).

Finally, the analysis drew on research in epistemic cognition, which involves how students think about the nature of math knowledge and knowing. In particular, I took into consideration the epistemological resources framework. This framework posits that different situations activate different manifold resources that frame how students think about the source and the nature of knowledge and how students participate in knowing activities (Hammer & Elby, 2002; Hammer, Elby, Scherr, & Redish, 2005; Rosenberg, Hammer, & Phelan, 2006). Other related labels for enacted epistemology include intuitive epistemology (diSessa, Elby, & Hammer, 2002), epistemic practices (Sandoval & Reiser, 2004), practical epistemologies (Sandoval, 2005), and epistemology in vivo (Umphress, 2012). Each term points to context-specific or discipline-specific practices, such as questioning claims, soliciting data, or transforming representations, conducted in situations in which students come into contact with knowledge. Researchers interested in enacted epistemologies do not by default expect enacted epistemologies to cohere into singular routines or worldviews. Instead, enacted analysts remain open to the possibility that knowing activities vary by context (see diSessa, 1993, for an analogous cognitive account, and diSessa, Elby, & Hammer, 2002, for an epistemology account). In the enacted framework, students' actions with respect to knowing signal to the researcher that

the student can and does believe knowledge can be treated in a certain way—the practices speak for themselves.

With these past frameworks and empirical findings in mind, I conducted iterative interaction analyses. The purpose of these analyses is to describe *how* participants build up interactions around epistemic cognition and attribution construction. I withhold from guessing at how participants feel about certain experiences or what specific thoughts participants have. Instead, I aim to see what cognitive and psychological experiences participants make relevant in their interaction. For example, participants may publicly invoke memory as an epistemic resource ("What happened here?") or they may invoke metacognition ("Do you think you understand this?"). Similarly, how participants orient their bodies and eyes to the environment may enact processes of perception and action that help generate their knowledge claims. In this way, I do not speculate on what specific thoughts and reasoning processes the tutors and students experience privately, but rather, describe the cognitive resources they make relevant in their talk and action, and how those experiences shape the knowledge construction process.

This approach involves honoring and attending carefully to the moment-to-moment organization of action, both talk and body, between participants. These actions provide markers not only of how participants seek out information, posit ideas, and build on each other's contributions, but also what cognitive resources participants would have needed to use to produce such an action. On this latter point, for example, if participants recall an experience or idea that is not visually available in the environment, we can confidently state that the participant drew on memory to create that action. The analyses that I conducted for this study attempt to recognize how participants publicly manifest routes toward knowledge construction and routes toward recognizing, attributing, and intervening in moments of struggle.

The main method for drawing conclusions from this data is to slow down the interaction using video players and to create multimodal transcripts of the second-by-second interaction. For the most part, I follow Gail Jefferson's transcript conventions, which are used in conversation analysis to describe the verbal channel of communication. I use the multimodal transcript conventions of Goodwin (2013) to mark the surrounding physical resources of eye gaze, gesture, physical action, and tool use. These transcripts disciplined my observations and gave me a public artifact on which to draw comparisons across dyads, serving as resources for generating the higher level categories and concepts that unfolded in the analysis. I adhere to the following transcript conventions in my analysis.

[ ]   Overlapping talk between speakers.

=   The talk of one participant combines together with the talk of another participant without a discernable silence in between.

(0.8)   Numbers in parentheses indicate the length of time in seconds between two utterances.

(.)   A small pause of less than half a second.

.   Falling intonation in the word that precedes the period.

?   Rising intonation in the word that precedes the question mark.

::   Colons mark when a sound is stretched out, and more colons signify that the sound is stretched for longer.

word   Underlining refers to sounds that are emphasized in terms or loudness or pitch.

↑   An upward arrow marks a significant rise in pitch.

↓   A downward arrow marks a significant fall in pitch.

><   Indicates that the talk between these symbols is compressed or rushed.

<>   Indicates that the talk between these symbols is elongated or slowed.

(*italics*)   A word in italics between parentheses signals a verbal description of the action or

             sound that the participants made.

Whenever dotted rectangles appear around words, accompanied by a straight line to an image, this signifies that the action in the image (described in the caption below the image) took place throughout the duration of the spoken word or phrase. Significant gestures and physical actions are marked in images with captions below that describe the action, and occasionally in text with italics. On occasion, I use white markings (such as arrows) on top of images to signal how participants move their bodies.

I attempted in the analysis to see common interactional structures during failure responses across the seven dyads. This means that my results section focuses on how a block of interaction in one dyad resembles a block of interaction in another. For example, if participants dedicate time in their conversation to proposing causes of an obstacle, I aim to describe the common features of their causal search processes. What falls into the background in this approach is a holistic account of the trajectory that each dyad takes. For now, I intend for my analysis to discover the common structures of the failure response process. In future projects, I intend to look closely at how these structures are assembled in sequence for specific dyads, how participants make meaning of these sequences in their interaction, and how educators and students can modify these sequences.

In my data analysis process, I examined three moments of struggle for each of seven dyads. I considered obstacles (or struggle/failure) to be *anything that disrupts fluid progress toward reaching the goal of finishing complete and accurate homework and/or acting according*

to social norms (defined by the community). These could include not knowing how to proceed on a problem, making a mistake on a math problem, becoming distracted from work, etc. After studying these moments of failure using the constant comparative method, I stopped looking at more data. I made this decision for two reasons. The first reason is that the purpose of the analysis is not to generalize within the after-school learning center or beyond the center, but to create a new way of understanding knowledge construction and failure responses in moments of interaction. These seven exchanges are not *fully* representative of the range of tutoring interactions that happen around failure. Nonetheless, it was important to me that I study practices with which participants routinely engage at the after school program. The episodes I selected are common interactions around failure but not a comprehensive portrait of all the failure experiences students have. Having tutored at the program for four years, I can comfortably describe these as ordinary moments of interaction during homework sessions. Because I have selected routine interactions, this will make it more possible to intervene in subsequent stages of this design research project at the learning center. Second, I had reached what Glaser and Strauss (1967) refer to as a point of saturation, not in the sense that new data could not have yielded new insights, but that the moments I had studied in detail had congealed in a way that created a coherent set of constructs. I saw common structures in how participants handled the obstacle, attribution, and intervention processes in their responses to failure, and these comparisons started yielding insights that called for revisions to attribution theory and for possible pedagogical design considerations at the after school program. In summary, the seven exchanges that I describe in the analysis section provide enough data for an incipient, and potentially generative, qualitative analysis of failure responses.

Chapter 4
Case studies in the social construction of failure

4.1 Failure in social interaction

I argue in this chapter that participants respond to obstacles in mathematics tutoring through three processes: recognizing the obstacle, proposing causes of the obstacle, and implementing an intervention to address the obstacle. These processes happen as part of the public practice of talk and action during mathematics tutoring sessions and participants can co-construct the actions that constitute each process. This work builds principally on prior efforts to view storytelling as one mechanism by which multiple participants build theories about what happened during a salient experience, why it happened, what resulted, and what should be done (Ochs, Taylor, Rudolph, & Smith, 1992).

In looking closely at the stories tutors and students tell together about obstacles, their causes, and their resolutions, this chapter moves the individual phenomenological framework of attribution theory—which studies attributions of failure through the thoughts that single individuals formulate on their own (Weiner, 1983; Graham, 1981)—into the social space of public conversation. The goal is not to understand how individuals think about failure long after it happens or through mediated surveys and interviews, but rather, to understand how people work together to publicly reflect and act on failures in the here and now.

As noted in the methods section, I attempt to see common interactional structures in how dyads respond to failure. I ask: How does a part of interaction in one dyad compare to a related part of interaction in another? The tradeoff is that this approach backgrounds the holistic account of the specific trajectory that each dyad takes. For now, I intend for the analysis to discover the

common interactional structures of the failure response process—not track the specifics of how participants create these sequences in their interaction or how educators and students can modify these sequences. In addition, I aim to formulate questions about the meaning behind these structures and their interconnections.

4.2   Chapter overview

I cover two contrastive case studies in this chapter, focusing on the complete process of constructing the obstacle, blaming the obstacle, and intervening to resolve the obstacle. I describe these cases with enough detail to introduce constructs and implications, and return to them more fully alongside the other five cases in the next chapter. The reason for starting with two case studies is to present the reader with an entry point into the framework I have developed to understand the social construction of failure. The goal is to see failure as a narrative co-constructed by the tutor and the student, and to see attributions as one process related to other processes in dyads' responses to failure. This chapter will also serve as an opportunity to introduce the aspects of the failure response process that I have observed across all seven of the dyads—but which I will discuss here in the context of two focal dyads.

Alongside accounts of each part of the failure response process, I speculate about the consequences of the choices tutors and students make, not for the purpose of providing definitive claims about how each choice influences the interaction, but for the purpose of generating questions about possible relevant consequences of the failure response process. Some of the mundane choices that participants make in their response to failure, if systematically and explicitly described, could be used to help educators think through how to productively modify their own failure response practices.

The broad interactional structure that I have observed across dyads during interpersonal conversations about failure involves three processes (see Figure 3). First, participants *describe* an action or inaction as an obstacle. These obstacles delay, jeopardize, or terminate the epistemic aims of creating and understanding what the community counts as knowledge. Because participants have discretion in labeling specific actions as obstacles, they actively construct the parameters of the obstacle.

After the tutor and student find an obstacle, they have the option of talking about the past and/or the future. In opening up the past, participants make available through talk and gesture what they believe caused the obstacle. In this second process, participants make causal claims about what actions in the past generated the obstacle just recognized. In opening up the future, participants plan a course of action to resolve the obstacle. In this third process, participants decide what actions are necessary and who should produce them in order to resolve the obstacle.
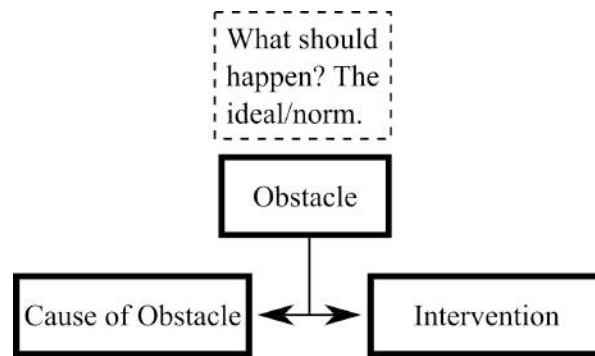
Figure 3: A diagram of the public failure response process.

Not all interactional responses to failure encompass all three processes. One process can be collapsed together with another or avoided altogether. In addition, the sequential order in which the interaction addresses each process varies. In each process, participants select some aspect of the homework experience to highlight, draw on some set of resources in the environment, and may rely on the outcomes of the other processes. In tutoring exchanges, the process of catching

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the obstacle, blaming something for the obstacle, and intervening to resolve the obstacle occurs between participants and within an activity in which one concrete goal is to achieve complete and accurate homework.

4.3   Introducing two case studies

The two dyads that I selected for these case studies are comprised of different students working with the same tutor. The selection of these cases allows for the recognition of some of the diversity in approaches taken by the same tutor in two different scenarios. In the coming pages, I start with an overview summary of what happens in each exchange, marking in broad strokes the obstacle, causes, and interventions that the dyads construct.

Figure 4: SZ and TC working on math homework.

To provide a preliminary overview of the first exchange, SZ and TC (Figure 4) are working on a multi-digit multiplication problem, 862 x 79, when SZ performs a minor addition error. "Five plus four is eight," she says, as she writes the number eight. TC vocally corrects the miscalculation, SZ blames her own confusion for causing the mistake, and TC responds with an intervention: "You gotta slow down. You gotta slow down." Moments later, TC provides a

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rationale: "But you need to slow down though. Like this. You're not even done here," pointing to an unfinished problem. The story about failure from SZ and TC involves constructing a math error as an obstacle, blaming it on confusion and speed, and slowing down to avert future obstacles.

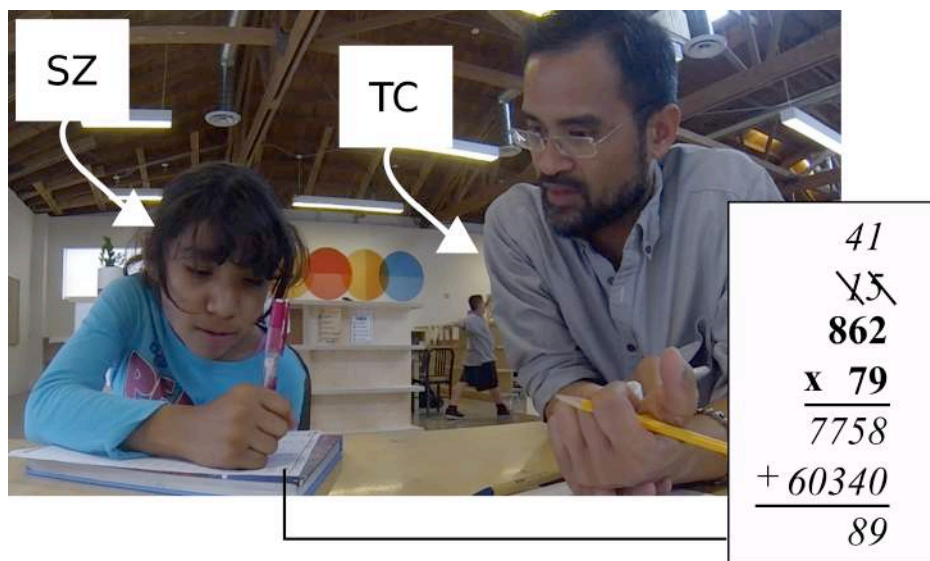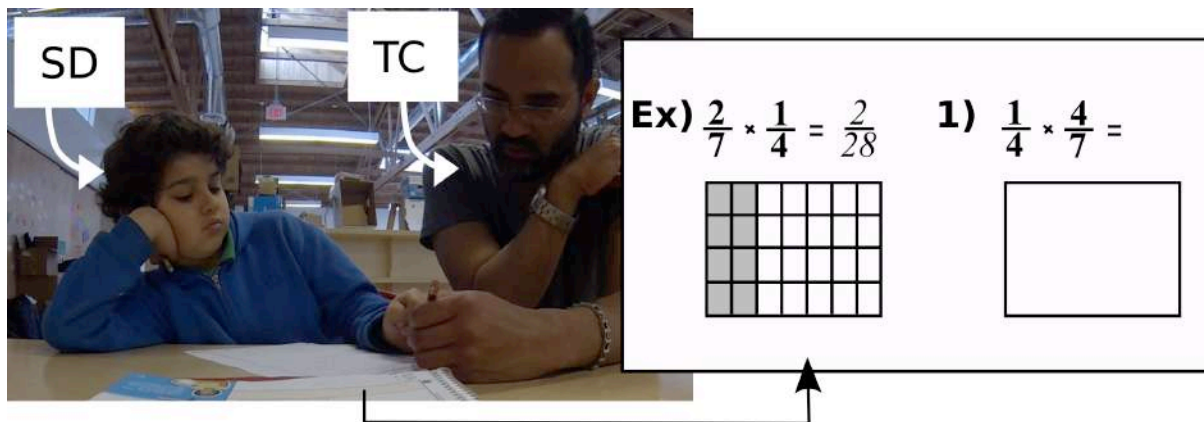
Figure 5: SD and TC working on math homework.

To provide a preliminary overview of the second exchange, SD and TC (Figure 5) are working on drawing a diagram of the concept of multiplication of fractions, specifically for the problem 1/4 x 2/7, when SD second-guesses his approach. To provide background on this problem, the normative answer involves drawing 4 horizontal rectangles in the open box and shading in one rectangle $(1/4^{th})$, and then drawing seven vertical rectangles and shading in four with a new color or pattern $(4/7^{th})$. The overlap in shaded areas provides the numerator of the solution and the total number of squares provides the denominator.

The exchange starts with SD vocally stating a plan, drawing six vertical lines, stopping himself, and saying, "Wait, do you?" looking up at the tutor. The tutor agrees something is wrong and they consider using a textbook, look together at the problem, and attempt to recall what happened in class. SD blames his own inability ("I suck at this") and later blames the tutor ("You're making me confused") after which TC proposes an intervention: "Do all the problems.

We'll do the picture later." SD and TC's story about failure has a student's lack of skill and a tutor's confusing actions causing uncertainty about a set of math actions, which is resolved by postponing the obstacle.

What are the common structures across these two episodes? In their talk and action, both dyads publicly mark an occasion as an obstacle, whether with an immediate correction ("nine") or a statement of uncertainty ("Wait, do you?"). The common structure behind the addition error and the math uncertainty is that the participants move to recognize some math action as (potentially) non-normative, as derailing the process of creating accurate mathematical knowledge. Attributions of failure trail the construction of the obstacle. Participants blame speed, confusion, lack of ability, and the fact that they are trying to "figure this out." Both dyads devote time to publicly articulating events that caused the obstacle, and both even disagree about the selection and veracity of those causes. To intervene, one dyad plans to hold future obstacles at bay and the other plans to postpone the obstacle.

In this chapter, I look closely at the interactional structure of these dyads' enacted responses to failure, parsing the construction, attribution, and intervention activities into smaller dimensions and discussing some of the possible implications of this fine-grained perspective. I provide two transcripts for the SZ/TC interaction and two transcripts for the SD/TC interaction. It is important to note that a series of events happens between the two SD/TC transcripts (which does not appear in the transcripts because it would make them prohibitively long). In the gap in the transcripts, SD and TC consider using a textbook, look together at the problem, and attempt to recall from memory what happened in class.

4.4 Co-constructing failure stories

In both dyads, we see tutors and students at work detailing an obstacle, blaming some arrangement of causes, and intervening to address the obstacle. Let us look at the details of TC and SZ's transcript (see Figures 6 & 7).

Figure 6: SZ writes and vocalizes a miscalculation and TC corrects the error. SZ attributes the failure to confusion. As she starts to erase the mistake, TC offers an intervention: "You gotta slow down."

TC: But you need to slow down though
SZ: Okay.
(1.5)
TC: Like this. You're not even done here.

TC points to unfinished math problem.

SZ: (.) Oops. (1.0)

SZ laughs and starts erasing mistake.

TC: [See? (*laughing*)]
SZ: [(*laughing*)   ]

Figure 7: TC offers an attribution of failure: too much speed caused SZ to leave a problem unfinished.

We see TC intercepting SZ's work with an immediate correction ("nine"), SZ stopping her work (lifting up her pencil), SZ providing an attribution ("I get confused, that's why"), SZ starting to correct her error (erasing the mistake), and TC offering an intervention ("you gotta

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slow down"). Their back and forth creates a situation in which a tutor notices and immediately corrects an obstacle, the student posits a cause of the obstacle, the student enacts an action to correct the math obstacle, and the tutor then proposes an intervention.

The second exchange, seen in SD and TC's transcripts below (see Figures 8 & 9), also displays participants co-constructing an account of failure and a plan to address that failure.

TC: You have to make it look like this (.) right?

TC points to image in example problem

SD: ↑Oh (.) yeah- but (.) an:d you do twenty-nine like (2.0) down?

SD gestures four consecutive downward thrusts with his left hand above the example.

TC: Okay:

SD: One (1.0) two (1.0) three (1.0) four (0.8) five (0.8). Wait do you:?

SD draws six vertical lines

SD looks up at TC

TC: Wait. (1.0) ºNo.º

Figure 8: SD expresses uncertainty over his math strategy and TC supports his hesitation.

TC: You don't remember it in class?
    (0.5)
SD: No:: (1.0) I su:ck at th[i:::s.   ]
TC: [Well ↑no. You don't.]

SD looks off to side and taps pencil on desk.

TC: You just. (2.5) We don't suck at it. I'm trying to-
    I'm trying to figure this out too.
    (0.5)
SD: (*click sound*) You're making it <u>confu:sed.</u>
TC: Wha:t?

TC asks the question and leans back while
SD begins to draw on his calendar.

SD: [°You're making me confu:sed.°   ]
TC: [Okay you know what? You know what we should do.]
    Check it out. Why don't we just uh:: (2.0). Why don't
    we multiply this first. Do all the problems. We'll do the
    picture later.

TC points to the numerical part of the math problem.

TC: How's that?
SD: Yeah:::

Figure 9: SD blames inability, TC blames "figuring this out," SD blames the tutor making him confused, and TC proposes postponing the obstacle.

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To summarize TC and SD's exchange, SD first constructs the obstacle ("Wait, can you?"), TC confirms the obstacle ("Wait. No."), and SD blames his own inability ("I suck at this"). TC rejects that cause ("No, you don't") and instead aligns himself with SD as a learner: "I'm trying to figure this out too." SD then proposes a new cause of the obstacle, that TC is creating confusion ("You're making me confused"), after which TC proposes to move on to the part of the problem that they understand and return to the drawing part of the problem later ("We'll do the picture later"). In this exchange, the student raises doubt about the veracity of his math actions and the tutor verifies his doubt; the student posits two attributions of failure, one of which the tutor rejects, and the tutor posits his own attribution; and the tutor suggests an intervention based on delaying the moment when they have to overcome the obstacle.

These tutor-student exchanges about trouble spots on homework are different from occasions in which a storyteller describes a past or fictive event to a rapt audience. Here, the participants create a story about failure in the midst of the failure experience. The recognition of the obstacle and the proposition to blame certain causes for the obstacle carve out a narrative as participants move through the activity. The experience is not registered internally and retold later, but constructed in the open with both parties contributing different ideas to different degrees in each of the three failure response processes.

To foreshadow some of the implications of this analysis, I will raise questions about who has power to construct an obstacle, assert causes, and build those assertions into interventions, especially on occasions in which the tutor and student disagree with each other about what caused the obstacle. I will also examine the influence of causal attributions on the design of interventions. I introduce these implications throughout this chapter and flesh them out more

fully in Chapter 5. For now, let us look closely at how these two dyads handle each failure response process: recognizing the obstacle, attributing causes to the obstacle, and intervening.

4.5 Process 1: Finding failure

My analysis of the process of constructing the obstacle posits five interrelated dimensions: Who marks the obstacle? When does that person mark the obstacle? What is revealed about the obstacle? What initial guidance is offered to reach the normative action? And does the obstacle refer to a prior non-normative action or inaction toward a future obstacle? I examine each process in its own section below, showing relevant excerpts from transcripts. As noted above, I raise questions about possible connections between aspects of the failure response process. These are meant to be generative questions to guide reflection on the failure response process.

4.5.1 Who marks the obstacle?

For failure to become a point of discussion between participants, someone needs to notice and call attention to an action or inaction as an obstacle. In other words, at least one of the participants must take action to recognize a problematic aspect of the activity. From a failure perspective, who takes this preliminary step is the person who recognizes the action as having the capacity to jeopardize the goals of the activity, which at this after-school program, are the epistemic aims of producing accurate math knowledge and understanding how to produce that knowledge.

In the first dyad (SZ and TC), we see the tutor constructing the obstacle, and in the second dyad (SD and TC), we see both the student and tutor constructing the obstacle (Figure 10). TC marks SZ's miscalculation as an obstacle (saying "nine") and SZ accepts his revision (pausing her work and saying "Oh yeah"). The verbal correction, laminated above the student's

ongoing writing, and which emerges out of the configuration of bodies positioned over the assignment, shows the tutor noticing and calling attention to an obstacle.
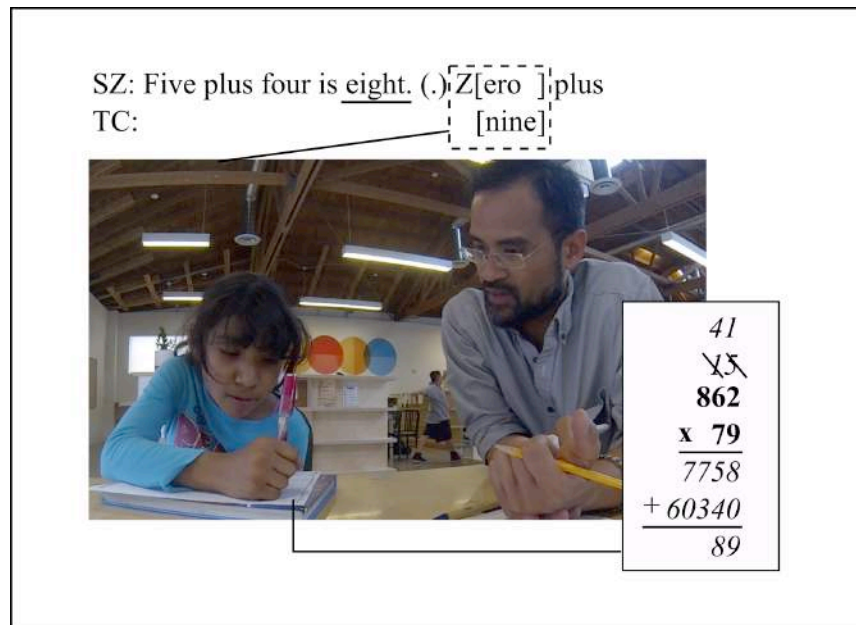
Figure 10: SZ vocalizes and error and TC immediately corrects it.

In the second dyad (Figure 11), the recognition of the obstacle unfolds through SD's question ("Wait, do you?") and TC's agreement ("Wait. No."). SD's verbal hesitation comes as he draws the six lines. The location of the tutor at the shoulder of the student, gazing down onto the homework, allows him to comment immediately on the obstacle. When TC verifies SD's hesitation, the two have co-constructed their awareness of the obstacle.

TC: You have to make it look like this (.) right?

Ex) $\frac{2}{7} \times \frac{1}{4} = \frac{2}{28}$ 1) $\frac{1}{4} \times \frac{4}{7} =$

TC points to image in example problem

SD: ↑Oh (.) yeah- but (.) an:d you do
twenty-nine like (2.0) down?
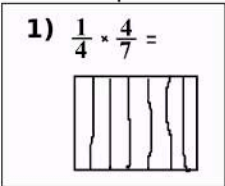
Ex) $\frac{2}{7} \times \frac{1}{4} = \frac{2}{28}$

*SD gestures four consecutive downward
thrusts with his left hand above the example.*

TC: Okay:
SD: One (1.0) two (1.0) three (1.0) four (0.8) five (0.8). Wait do you:?

1) $\frac{1}{4} \times \frac{4}{7} =$

*SD draws six
vertical lines*

SD looks up at TC

TC: Wait. (1.0) ºNo.º

Figure 11: SD expresses uncertainty over his math strategy and TC supports his hesitation.

Implications. There are at least two possible implications of how participants navigate this aspect of the failure recognition process. First, interpersonal actions around failure denote who decides and communicates that failure has taken place. How often do tutors decide that a

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student has failed, how often do students decide that they have failed, and how often do they decide together? An answer to this question would provide a basic account of who notices failure and who has the power to label math actions as failure. If students frequently yield to tutors' discretion in finding obstacles, then what would this mean for students' capacity to locate obstacles independently or in other settings?

Second, the person who finds the obstacle, depending on how much he/she knows about its resolution, is in a strong position to decide how much to describe about the obstacle and thus how to direct the failure response process. TC immediately reveals to SZ both her mistake and its resolution, opening up the opportunity to swiftly consider its past causes and to consider future interventions. TC and SD, in contrast, do not state a resolution to the obstacle—the causes they later posit ("I suck at this," "I'm trying to figure this out too," and "You're making me confused") function as attributions of their inability to resolve the obstacle. In multiple exchanges in the following chapter, we see tutors holding back from revealing a description of the obstacle, which creates a situation in which the student must find the obstacle. In short, who notices the obstacle and how much they describe about the obstacle can significantly shape the trajectory participants take in response to it.

4.5.2 When do participants mark the obstacle?

How do participants time the construction of the obstacle relative to when the obstacle manifests? In both of the cases above, participants recognize the obstacle moments after it emerges. SD flags his uncertainty at the same time that he produces the physical action of drawing vertical lines, and TC flags SZ's miscalculation less than a second after she vocalizes and writes it. The upshot of publicly recognizing the obstacle nearly simultaneously with its emergence is that the obstacle and the moments that lead up the obstacle are still fresh in

memory. The pencil marks students had made on the page (numbers in SZ's case and lines in SD's case) are still located in front of the participants and the thoughts and actions they had just taken are still retrievable in memory. In the subsequent chapter, we see cases of obstacles recognized by participants well after the obstacle initially appears.

Implications. What participants can attribute to the obstacle, and hence what guides their intervention, is dynamically related to when they notice the obstacle. With greater temporal distance from the obstacle, different perspectives on its etiology may emerge and different cognitive demands on how to investigate that etiology would take place. Importantly, the embodied infrastructure of the setting, with student and tutor huddled around the homework looking down onto the homework page, allow and even encourage tutors to swiftly flag mathematical obstacles. Whether the immediate recognition of an obstacle is valued and how it influences the remaining causal search and intervention stages may be important considerations.

4.5.3 What do participants reveal as the obstacle?

When tutors or students notice an error on math homework and decide they want to make that obstacle public, they have to describe it with some level of granularity. In the first dyad, TC homes in on the addition mistake with a single word ("nine") that corrects the mistake. The action brings into the open, as precisely as possible, the math calculation that TC recognizes as an obstacle and the resolution to it. In contrast, TC and SD notice that an obstacle exists somewhere in their recent math actions, but they never publicly describe which aspects of their past actions are implicated in the obstacle (whether because they don't know themselves or because the tutor holds back). SD formulates a plan ("you do twenty-nine down"), TC "okays" the plan, SD executes and then second-guesses the plan ("wait, do you?"), and TC agrees that the

plan is flawed ("Wait. No"). According to TC and SD, an obstacle exists somewhere in that plan, but they do not locate a specific flaw.

Implications. Recognizing that an obstacle exists, but not which math actions should be understood as non-normative, means that participants still have to sort out the task of finding out what part of the activity has failed. TC and SD fall into this category, devoting several turns (not in the transcript) to considering using a textbook, looking together, and trying to recall in memory what happened in class. In contrast, with a precise account of the obstacle, participants can devote attention to understanding its causes and attempting interventions to resolve the obstacle.

Looking across the first three dimensions of the obstacle recognition process, we could ask a series of generative questions. How might the causal search and the intervention processes vary if (1) a tutor notices and immediately describes the obstacle, (2) a student notices but does not describe an obstacle until 30 minutes after the obstacle first appears, (3) a tutor notices and precisely describes an obstacle 24 hours after it appears, or (4) a tutor notices and withholds describing an obstacle seconds after it appears? How would these configurations impact what participants can understand about the etiology of the obstacle and hence possible sustainable resolutions? Can participants search for causes of an obstacle when the person who noticed the obstacle withholds an account of it? I intend for these questions to signal the range of possible configurations of these dimensions and the possible pedagogical value of reflecting on their arrangement.

4.5.4 What initial guidance is offered to reach the normative action?

How much do tutors initially tip their hand to reveal the normative action that should take place? In some cases, the obstacle is promptly corrected. Immediately after SZ's mistake, for example,

TC describes the math action ("nine") SZ should take. This happens half-a-second after SZ writes and says aloud, "Five plus four is eight." TC's statement resolves the obstacle in the very same verbal utterance in which SZ comes to know about the obstacle. The second dyad, in contrast, comes nowhere near resolving the obstacle of drawing multiplication of fractions during their exchange.

What are the consequences of leaving an obstacle unresolved for a later intervention versus resolving the obstacle up front? These two options focus attention on different aspects of failure. In the former delayed approach, students have to search for a way to correct a mistake. In the latter, the tutor who finds the obstacle fixes it promptly, denying the student the chance to self-correct. Would the quick fix free up time for other aspects of the failure response process? In TC and SZ, after a swift resolution to the obstacle, they posit causes of the obstacle and propose interventions to stave off future obstacles. Elongating the process of resolving the obstacle, in contrast, means that participants need to focus their attention on strategies to overcome the roadblock. Would those participants then have less spare capacity (or would have to delay the chance) to search for causes of the initial obstacle?

As noted above, I intend to raise these observations as possible interconnections between aspects of the failure response process, not for the purpose of proving them as definitive associations, but rather, to suggest that choices participants make in regard to each of these features could plausibly influence other features of the failure response process.

4.5.5 Is the obstacle in prior action or future inaction?

Do student's past public actions become obstacles or do students pause ahead of an obstacle without publicly attempting it? In both of the cases above, students attempt a series of mathematical actions (SZ's "five plus four is eight" and SD's drawn lines) and then locate an

obstacle in their prior actions. We will see multiple cases in the next chapter of students pausing ahead of an obstacle without working through it publicly.

Implications. What are the consequences of these two routes for the subsequent causal search process? SZ, SD, and TC all posit causes of the obstacle after they have witnessed or experienced what happens when the student fails to overcome it. SZ has already said, "Five plus four is eight," and SD has already attempted a strategy of drawing vertical lines in a rectangle by the time both students provide accounts of what caused their mistakes. In other words, the students and their tutor have data from the students' own previous attempt and can use that information to support the causal search process. In contrast, without seeing or experiencing a first attempt, participants have to infer why the student is presently unable to route around the obstacle, marking an imagined or prospective attribution of failure. In addition, the choice of whether to try or to hold back makes a strong statement about what the community considers to be the minimum amount of work needed before something is considered an obstacle.

4.5.6 Summarizing the obstacle recognition phase

Why highlight these five dimensions of the obstacle recognition phase? These features of the preliminary process through which participants notice and describe an obstacle represent salient choices in their own right and they also plausibly influence the subsequent processes of causal search and intervention. They are issues in timing, granularity, agency, directedness, and effort. When do we find obstacles, with what precision do we label them, who finds them, how much initial guidance do we provide toward the resolution, and how much have we already publicly tried to overcome the obstacle? In order to understand the context in which participants blame obstacles in live discourse, we need to first understand what participants know about the obstacle and about the student's relation to that obstacle.

4.6 Process 2: Causal search

After the tutor and student make relevant in their conversation that an action or inaction should be considered an obstacle, a window opens up in which participants can attribute causes to the obstacle. Participants can propose singular causes of the obstacle or chains of causes, and in their language and gesture, tie these causes to specific locations in the world. This process can take place at different temporal points in the failure response process, whether before participants have resolved the obstacle or after participants have resolved the obstacle. Below, I introduce these dimensions of the causal search process in detail, referencing relevant parts of the transcripts.

4.6.1 Positing causes and chains of causes

SZ and TC, after correcting SZ's addition error, blame the mistake on different causes (see Figures 12 and 13). SZ blames confusion ("I get confused that's why") and TC blames speed ("But you need to slow down though").

Figure 12: SZ credits her own confusion for causing the mistake.

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TC: But you need to slow <u>down</u> though
SZ: Okay.
(1.5)
TC: Like this. You're not even done here.

TC points to unfinished math problem.
SZ: (.) Oops. (1.0)

SZ laughs and starts erasing mistake.
TC: [See? (*laughing*)]
SZ: [(*laughing*)   ]

Figure 13: TC credits SZ's fast pace for causing the mistake.

Both participants vocally stress causality in their communication, with SZ explaining "that's why" and TC tying his statement about speed to a past error ("Like this. You're not even done here"). These acts of communication signal that a past event caused an addition error and an unfinished math problem. The disagreement about what caused the obstacle (confusion or speed)

points to the speculative nature of this work—it may not be possible to point to a single cause of an event, as there are often multiple simultaneous causes of actions and also chains of causes going back in time (Hesslow, 1988).

TC and SD also disagree about the cause of SD's math struggle. TC and SD blame lack of ability, lack of understanding, and confusion (see Figure 14).

TC: You don't remember it in class?
     (0.5)
SD: ⌈No::⌉ (1.0) I su:ck at th[i:::s.   ]
TC: [Well ↑no. You don't.]

SD looks off to side and taps pencil on desk.

TC: You just. (2.5) We don't suck at it. I'm trying to-
     I'm trying to figure this out too.
     (0.5)
SD: (*click sound*) You're making it <u>confu:sed.</u>
TC: ⌈Wha:t?⌉

TC asks the question and leans back while
SD begins to draw on his calendar.

SD: º[You're making me confu:sed.º   ]
TC: [Okay you know what? You know what we should do.]
    Check it out.

Figure 14: SD blames inability, TC blames "figuring this out," and SD blames the tutor making him confused.

SD proposes the first cause, often highlighted in attribution theory literature, which is lack of ability ("I suck at this"). The statement takes a complex discursive environment that

spans two people, a physical worksheet, norms of the after school program, and all of the cognitive resources involved in the homework process, and locates a holistic failure point in the student himself. The tutor quickly pushes back: "Well no. You don't. You just. We don't suck at it. I'm trying to figure this out too." Not only do TC's statements explicitly reject SD's attribution of inability ("You don't"), but they also propose a new attribution of failure: "I'm trying to figure this out too." The comment suggests that it is not "sucking" at "this" math that is causing the problem, but rather, the act of working to attempt to understand the mathematics.

Following these attributions, TC proposes yet another attribution, "You're making it confused," followed by, "You're making me confused." The statement provides a causal chain: the tutor causes confusion in the student, which in turn causes the math obstacle.

Implications. This analysis raises a few important considerations regarding the causal search process. The first point is that what is blamed for the obstacle can vary over time and across participants as tutors and students make public what they consider to be the cause of the obstacle. Second, that participants interleave thoughts about attributions of failure within their discourse suggests that the action is doing some kind of work, whether dissolving/assigning responsibility, guiding the intervention, or understanding the struggle. Third, participants can explicitly reject causes that others propose. Fourth, what participants posit as causes of the obstacle can motivate the intervention. With the etiology of the obstacle in mind, an intervention can address how to prevent the cause from taking place or how to meaningfully respond when it does. In this way, stories about failure, co-constructed live by the tutor and student, can encompass contrasting and generative statements about what creates failure.

4.6.2 Where are causes of failure located?

Attribution theorists have long recognized that the location of causal ascriptions carry with them assumptions about who or what is expected to change in order to circumvent the obstacle. In grammar and in gesture/action, participants encode where the causes of their failures are located. In SZ and TC, SZ marks that "I" get confused and TC marks that "you" have to slow down, both of which locate attributions of failure inside the student. SD, similarly, begins by marking his attribution of failure, low ability, in himself ("*I* suck at this"). In his second attribution statement ("*You're* making *it* confused. *You're* making *me* confused"), SD spreads the locus of the cause of confusion across the tutor and himself in the activity, stating that the tutor ("You're") is creating confusion in himself (swapping out "it" for "me").

Implications. Whereas the psychology literature has often framed outcomes as the product of singular causes from singular locations, the participants in both of these exchanges challenge these assumptions. In positing multiple causes, and in the case of SD and TC, positing causes that stretch across both the tutor and student, participants co-construct complicated, if not contradictory, stories about the causes of their failure. The tutors and students in these conversations are creating stories about failure that refuse simple accounts of failure originating from a singular location. This observation raises a question I mentioned earlier: Who has the power to have their attribution persist moving forward, guide the intervention, and become appropriated individually in post hoc stories? Moreover, because language ties attributions to specific loci in the setting, this observation raises the question of the political nature of co-constructed attributions of failure: assuming that participants have limited resources and limited time, who will be expected to modify their contribution to the activity to dissolve the obstacle?

4.6.3 When are causes of failure discussed?

Post hoc stories about failure may not provide temporal information at a fine-grained enough level for researchers to know when participants started attributing their failures to specific causes. In the obstacle recognition process, I noted that students and tutors can label an experience an obstacle before students have even publicly attempted to act on it (we will see examples in the next chapter). The same can be said for attributions of failure. If an attribution of failure reaches the surface of conversation before the student has worked through the obstacle, then the participants are necessarily simulating, imagining, or reasoning about what they believe is holding back the student—in what we might call prospective attributions of failure. This characteristic of the causal search phase is salient not only for the degree to which participants may have to speculate to posit a cause, but also in the sense that a prospective attribution of failure may motivate a specific intervention misaligned with the actual capacities of the student. We will see examples of these types of attributions in the next chapter.

In contrast, in both of the cases above, the students and the tutor posit causes of failure after the students have publicly worked to solve the math problem on their homework. This means that participants have evidence at hand about what happened in the student's first, independent attempt and can posit a cause based on what they observed or experienced in that attempt. There is no guarantee, of course, that observing a first attempt provides enough information to formulate the correct attribution of failure. The search for causes can still lead to incomplete or partial proposals.

4.6.4 Summarizing the causal search process

Tutors and students, in confronting obstacles to math progress, can publicly provide and disagree about descriptions of the causes of the obstacle, whether that be confusion, working too quickly,

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the tutor's actions, lack of ability, or the need to figure the problem out. These causes can appear in chain-like sequences, as in the case of SD looking to the tutor and explaining, "You're making me confused," which stretches the link of actions that creates the obstacle across the tutor and himself. The expression of alternative causes, or disagreements about causes, makes a strong statement about the subjectivity of the causal search process, given that multiple events often simultaneously cause an outcome and causal chains extend back into the history of the activity. Participants tie these attributions of failure to specific locations in the activity through their language and gesture, setting up an expectation of who will be asked to modify their practice in the intervention. Finally, the degree to which participants have to speculate on the causes of an obstacle may be dynamically related to whether the students have publicly attempted to overcome the obstacle or pulled up short ahead of the obstacle.

4.7   Process 3: Intervention

Whereas the obstacle recognition process involves how/when participants describe the obstacle and the causal search process involves attributing causes to the obstacle, the intervention process involves acting in new ways to overcome the obstacle. The intervention process is necessarily forward thinking, designed to plan and/or attempt a new strategy to return to making progress toward the goal. The intervention also has the capacity to reflect a natural extension of the obstacle recognition and causal search processes, targeting the specific obstacle and the causes of that obstacle.

The failure intervention process involves three dimensions: What parts of the intervention are students expected to control? Does the intervention focus on past public actions or future actions? And what actions are needed to route around the obstacle? In the two case studies in this

chapter, we find two distinct intervention strategies, one focused on avoiding obstacles in the future and one focused on delaying the immediate obstacle.

4.7.1 What parts of the intervention are students expected to control?

Interpersonal activities commonly involve divisions of labor in which participants contribute different ideas, actions, or materials that combine to create a valued outcome. How activity in the intervention is divided among the tutors and students resembles what attribution theorists have designated the "controllability" of causal ascriptions. Phrased simply: Is the cause of the obstacle something that students can influence? The division of labor in the activity describes what tutors control and what students control in the intervention that targets the proposed cause of the obstacle. When the intervention ignores the causes of the original obstacle, but still takes the participants toward the normative end goal, then the intervention may still parse the activity along actions controlled by the student and actions controlled by the tutor, but these actions would not address the proposed cause.

In SZ and TC, the plan for the intervention targets a cause that TC posits, the idea that SZ has been working too quickly (see Figure 15).

Figure 15: TC proposes an intervention in which SZ slows down.

In the prior section, we saw TC phrase his account of the cause in the language of an intervention, "You need to slow down," but he added, "Like this. You're not even done here," which tied the element of speed to one of SZ's prior mistakes. TC's other comment (above), "You gotta slow down," repeated twice, provides a plan for SZ moving forward. Speed as an attribution of failure and slowing down as an intervention become for TC a packaged account of and resolution to failure, invoked in two moments of interaction, targeting first a calculation error (five plus eight) and second an unfinished problem. The division of labor in the intervention activity is straightforward: TC invents the plan and SZ executes the plan. From a controllability perspective, this simple command in speech suggests that TC has the capacity to control her speed on upcoming problems.

Taking into account what happened during the obstacle recognition process, we know that TC has already corrected SZ's addition mistake and that SZ has already agreed that the correction is accurate and started erasing her mistake. SZ has thus already resolved her obstacle

by the time TC suggests that she slow down. The suggestion, then, functions as a guideline not to settle the present mistake but to avoid upcoming mistakes. Interventions designed to curb the possibility of repeat obstacles in the future mark the stability of the cause, another factor that attributions theorists have considered relevant to the way participants understand causal ascriptions. TC's intervention suggests that SZ's fast speed will be stable and cause additional mistakes moving forward. The verbal phrase marks both the controllability of the action and the likelihood that the causes targeted by the intervention will remain stable throughout the homework session.

SD and TC adopt a different approach to their intervention. SD has already blamed himself for lack of ability, TC has blamed the fact that they are trying to figure out the problem, and SD has blamed TC for causing confusion. After this battery of causal ascriptions, TC proposes an intervention that pushes the obstacle further into the future (see Figure 16).

Figure 16: TC proposes an intervention in which he and SD focus on what they know and postpone the obstacle.

TC proposes, "Why don't we multiply this first? Do all the problems. We'll do the picture later," in effect focusing energy on math activities they can competently solve now and returning to the hard part of the problems later. The plan is silent on how labor will be divided. In proposing that the participants skip all of the drawing problems, the intervention also embeds within it an assumption that upcoming fraction multiplication drawings on the assignment will pose a similar problem—the cause of the obstacle of drawing multiplication of fractions is not specific to the present problem but stable across all of the problems on the worksheet.

4.7.2 Does the intervention focus on past or future actions?

The difference between past-oriented and future-oriented interventions is not in whether students are asked to try something new—the point of an intervention is to change something, however small, to overcome the obstacle on the path to completing homework. The difference between the past-oriented intervention and future-oriented intervention is in how the participants treat the students' prior attempt. In some cases, the participants re-immerse in the past attempt, looking over the decisions the student made to motivate the discovery of what could have happened differently. This past-oriented intervention re-simulates aspects of the student's prior actions to see a new possible action moving forward. In contrast, other interventions move forward into new actions without re-invoking the actions that predated the obstacle. In these cases, the student and tutor plan or attempt a new action, but they do not attempt to see how that new action connects with the student's prior action.

TC's proposed intervention for SZ marks a future-oriented action. In requesting that SZ slow down, TC points out a new pace with which SZ should work through her homework. The intervention does not attempt to recreate the moment before SZ made a calculation error, for example, by considering how the addition calculation could have happened differently had SZ

been working slowly. Nor does the intervention ask SZ to repeat the problem at a slower pace. In SD and TC, similarly, TC's proposal to postpone the obstacle does not re-enter the moments leading up to the obstacle, but rather, moves forward with a new action. In the subsequent chapter, we will see multiple examples of tutors drawing students back into the math actions that preceded the obstacle as a way to draw out a resolution to the obstacle.

Because attributions of failure are necessarily about formulating claims about the past causes of obstacles, it is relevant to track the extent to which interventions can, in parallel with attributions of failure, re-open the past through reflections on written work and memories of prior experiences as grist for formulating strategies to rectify the obstacle. Past-oriented interventions offer the possibility of bringing students back to the fork in the past where something went wrong, and to provide a second chance to correct the prior mistake. Future-oriented interventions, as in the case of, "You gotta slow down," can also target proposed causes of the obstacle (in SZ's case, working too quickly), but do so in a way that does not re-engage with the past moments in which the cause manifested.

Implications. To raise a few possible implications of this dimension, I can note that re-entering the past is quite straightforward in some cases, as when students are asked to return to a problem and solve it again to correct a past math mistake. Why is it natural to have a student re-enter the past and correct a mistake on a math problem, but it is less intuitive to have a student, such as SZ, redo the problem that she has correctly solved but at a slower pace? Do these two types of interventions value to different extents product versus process, some obstacles over others, or past obstacles versus future obstacles? These two routes may provide different ways of uncovering causes of failure and learning to resolve them.

4.7.3 What is needed to overcome the obstacle?

Interventions provide an account of what experiences students need on the path around an obstacle. Whereas the controllability section of this chapter provides an account of what experiences the tutor controls and what experiences the student controls, this dimension attempts to describe how what the two participants control and plan presents a strategy that will be enough to overcome the obstacle. For example, TC proposes the idea of slowing down and SZ is expected to act on the idea. What does this intervention say about what the student needs in order to overcome the obstacle? The tutor's verbal proposal suggests that the student needs an idea of slowing down in order to enact the action of slowing down to stave off future math obstacles. The intervention suggests that the student does not need new math ideas, a sharper pencil, renewed motivation, feelings of regret when making mistakes, etc. Instead, the student needs an idea to slow down, which will trigger her working at a slower pace. SD and TC postpone their discussion of what they will need in order to overcome their obstacle of drawing multiplication of fractions.

The idea of what is needed to overcome the obstacle is dynamically connected but distinct from the notion of controllability. To continue with the above example, we can think about different ways that the need to slow down could have been proposed in the intervention. The student herself could have said, "I need to slow down. I'm making too many careless mistakes," a plan whose parts are both proposed and enacted by the student (in contrast to the division of labor in the present exchange in which TC proposes the idea and SZ is expected to enact it). The necessity to slow down may be commonly flagged across different conversations, but who is expected to control the production and execution of that plan may vary. In examples in Chapter 5, we will see interventions that suggest students need new math ideas, others that

suggest students need to re-experience the moment before the obstacle, and others that suggest that the student needs to be coerced. Each of these interventions can have different divisions of labor depending on how much of the intervention students control and how much the tutors control.

4.7.4 Summarizing the intervention process

The process through which participants formulate plans to respond to math obstacles involves dividing the labor of the activity in such a way that students take some control of the process, focusing on past attempts or future actions, and presenting some set of experiences that students need to move past the obstacle. The extent to which interventions plan for similar upcoming obstacles also signals whether participants expect the obstacle to repeat, a mark of the stability of the causes of the obstacle. In both of the dyads above, the interventions were designed in such a way that participants dealt with the likelihood that the obstacle would reappear on future work.

The intervention wraps up the story about failure, which contains elements of what counts as obstacles, where obstacles come from, and how to resolve them. Who has the power to formulate the plan and how the plan makes assumptions about students' capacities and needs together provide critical markers of the way learning communities think together about resolutions to failure.

How are attributions connected to interventions? TC proposes that SZ slow down and SZ is expected to realize that plan. The tutor, in this way, formulates a plan for an intervention that spawns from his own attribution of failure, and ignores SZ's suggestion that confusion caused her calculation error. Does SZ have the capacity to slow down, does she need to slow down, and should the intervention also target her confusion? Who has the power to make these decisions? In the second dyad, TC proposes an intervention in which he and SD postpone the obstacle and

SD agrees with the plan. Decisions about who will control what in the intervention and what experiences SD will need to learn to draw a diagram of multiplication of fractions are both pushed into the future. Does this intervention suggest that SD is correct in attributing failure to his own inability? Does the intervention also suggest that SD is correct in attributing failure to the tutor causing confusion? What does the decision to postpone the obstacle say about the student's and tutor's capacity to figure out the problem together?

4.8   Summary of the social construction of failure

The purpose of this chapter is to introduce the reader to three of the processes that can be involved in social interactions aimed at responding to failure, in addition to the dimensions that comprise each of these processes (see Figure 17 below). In drawing attention to connections between the three processes, I have not intended to provide causal or correlational evidence that changes to the dimensions of one process automatically change another process. Instead, my goal has been to formulate plausible ideas about how choices participants make when navigating their responses to failure may constrain or afford other aspects of the process and make profound statements about who has power and agency during failure.
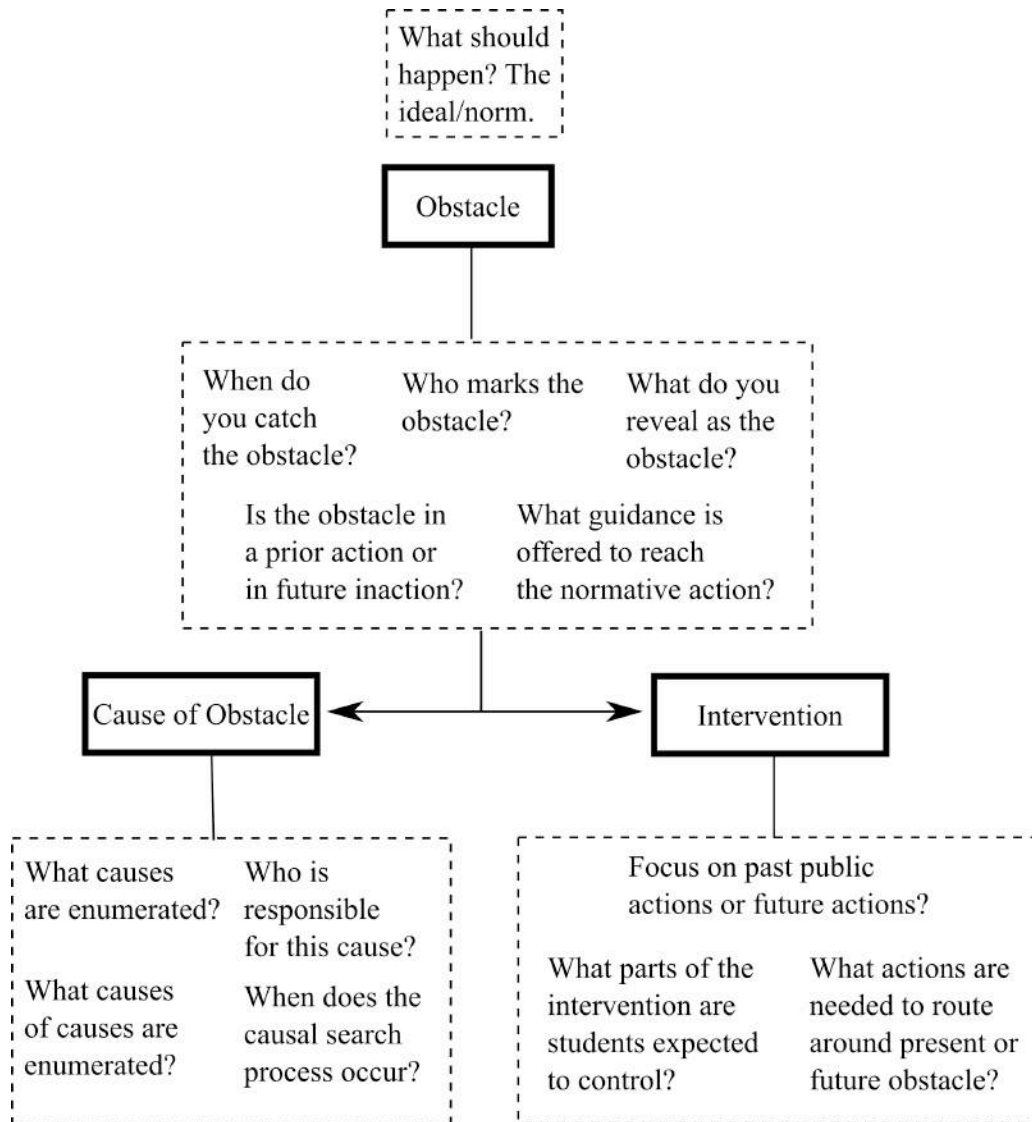
Figure 17: The flow chart above shows how the causal search and intervention processes can both take place following the recognition of an obstacle. Each of the three processes has its own set of dimensions, captured with sets of questions in each dotted-line rectangle.

I summarize features of the failure response process in the following way. When participants note the presence of an obstacle, they suggest that some other normative or preferred action should be happening. For example, instead of writing the number eight (the obstacle), the student should have written the number nine (the normative action). I argue that the process of recognizing obstacles involves an *interlocutor* (tutor, student, or both) flagging an obstacle *with some level of granularity* (labeling a specific obstacle or stating that some obstacle exists). *How*

much time elapses between the presence of the obstacle and the labeling of the obstacle, *how much initial guidance* toward the normative action participants provide, and *whether participants have publicly attempted the obstacle* (or paused ahead of it) all mark salient dimensions of the obstacle recognition process. The search for what to blame for the obstacle can involve an interlocutor positing *causes* of the obstacle and *causes of those causes* located *within or outside* the participants. The causal search process can take place during, immediately after, or long past the moment when participants find the obstacle. Lastly, the intervention process focuses on the students' *past* public attempts or *possible* future attempts, giving the student *control* over some aspect of the intervention process and suggesting what actions are *needed* to overcome the obstacle. Taken together, these dimensions amount to a story that connotes whether the obstacle is expected to recur—a mark of *stability* of the causes.

In Chapter 5, I explore a broader diversity of failure response processes. The tutors and students find obstacles in actions performed in the distant and immediate past, and in inactions ahead of possible future obstacles. New causes of failure include a friend's distracting actions, math inscriptions on the page, and difficult math problems, all of which emphasize the spread of locations of causes and their chains in activity. Finally, new types of interventions include coercion to correct a behavior and re-immersion in past math actions to uncover the normative solution. In Chapter 7, I focus on the implications of these observations, making explicit comparisons to traditional accounts of reflections on failure in attribution theory and proposing questions and considerations for educators. For now, let us turn to Chapter 5, which will apply the concepts introduced in this chapter to a wider sample of seven dyads, including the two just discussed in this chapter.

Chapter 5
Causal reasoning and failure in social interaction

In this chapter, I discuss how seven dyads address obstacles during mathematics tutoring. I focus on the obstacle, attribution, and intervention processes in separate sections but take into account the context of the other processes. At the culmination of the chapter, I address interactions between these processes. The goal of the chapter is to show variability across all seven cases.

5.1   Process 1: Finding failure

I define obstacles (or failure) according to the local context of the after-school learning center: *anything that disrupts fluid progress toward (1) reaching the goal of finishing complete and accurate homework and/or (2) acting according to social norms (defined by the community).* The kinds of failure experiences that participants recognize—incorrect math procedures, moments of distraction, uncertainty over what to try next—are experienced as such because they interfere with progress toward achieving goals at the learning center. Pausing to recognize, process, and respond to an obstacle, then, is itself an attribution of potential failure. That is, participants envision a goal—accurate homework—and attribute some action in the present to jeopardizing that goal (see Figure 18). Importantly, I study actions that participants treat as obstacles, evidenced by their efforts to intercept an activity and suggest or search for a different approach.
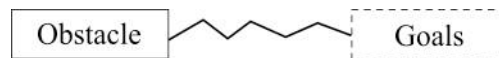
Figure 18: The decision to stop, address, and attempt to change an event during homework reflects the participants' recognition that the event is an obstacle jeopardizing their chance of achieving the goal of complete and accurate homework.

How are obstacles to progress recognized? As noted in Chapter 4, someone must flag the obstacle and describe the obstacle at some level of granularity. In four cases, tutors recognize the

obstacle, and in three cases, students recognize the obstacle. Starting with the first four, we see the tutors constructing the obstacle and providing some contours that define the problem. TC and TM flag obstacles (miscalculation and distraction) with immediate suggestions for how to correct them (Figures 19 and 20), while TF and TN flag obstacles (missed math step and wrong answer) without providing immediate contours toward the normative math action (Figures 21 and 22). I have given each dyad's exchange a title (in bold, all caps).

LAUGHTER CASE

Figure 19: TM gives the shush gesture/sound (the suggested correction to the obstacle of laughter) to SF off screen.

ADDITION CASE

SZ: Five plus four is eight. (.) Z[ero] plus
TC: [nine]

Figure 20: SZ proposes that 5 + 4 = 8 and the teacher immediately corrects that answer by saying, "nine" (the suggested correction).

RECIPROCAL CASE

Figure 21: TF, who is watching SJ solve a problem, tells her to hold on (flagging the problem without offering a correction).

Figure 22: TN examines SG's completed homework and then asks SG to look over the answers with her (signaling a problem without suggesting a correction)

Recognizing the obstacle

The common structure across these episodes is that *tutors* flag events they consider to be obstacles to progress. In the laughter case, TM gives the "shush" gesture and sound to SF who is off screen, calling attention to something problematic (laughter) in SF's actions. In the addition

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case, SZ proposes that 5 + 4 = 8 and her tutor immediately corrects that calculation by stating "nine." In the reciprocal case, TF is watching SJ solve a problem and tells her to "hold on." And in the missing zero case, TN, who has just examined SG's completed homework, asks SG to look over the answers with her.

Implications. In all four cases, the tutor assumes responsibility for recognizing the mistake and suspending or altering the activity. One of the implications of this dimension of the obstacle recognition process is that the event threatening the likelihood of achieving complete and accurate homework could have gone unnoticed by the student had the tutor not drawn attention to the event. What does this basic dynamic mean for who will routinely notice failure, how students find moments of failure on their own, and who has power to classify something as failure?

The tutors' conversation moves, by constituting events as obstacles, signal the value of overcoming them. The participants turn students' actions into obstacles by suspending the activity to consider alternative courses of action or by immediately redirecting activity. The message is that out of all the events happening during the homework session, the tutors are declaring that these events warrant different approaches. Adding up digits incorrectly (SZ), laughing loudly during the homework session (SF), not following all of the steps in division of fractions (SJ), and missing a problem on a double-digit division assignment (SF) are all constituted as actions that need repair. The upshot is that the recognition of struggle opens up a possibility: achieving a normative, correct, or proper way to handle the situation different from the action the student has taken in the past.

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Guiding toward the solution

The tutors' actions to suspend the activity describe with varying amounts of detail what went wrong and what the normative or preferred action should be. The tutors in the first two dyads, TC and TM, not only flag the obstacle, but they simultaneously provide contours for how the student should resolve the obstacle. More precisely, the tutors package the recognition that something went wrong together with a suggestion for how to remedy the situation. In one case, TC instantly declares the solution to SZ's addition problem (saying "nine"), and in the other case, TM immediately offers guidelines for how to behave in a new way (saying "Shhhh," the sign for quieting down). Despite that one involves an addition procedure and the other an experience of laughter, the tutors' approaches to recognizing these obstacles offer parallel structure: the preferred action is to do something (write the number 9 and quiet down) different from what the student just did (writing the number 8 and laughing loudly).

In contrast, the latter two episodes offer more concealed approaches to flagging the normative action that should have happened. TF flags that SJ should pause, but TF does not offer contours for how SJ should correct her math strategy. Similarly, TN asks SG to direct attention back to a completed assignment, a signal that something went wrong on the assignment, but she gives no indication of what is wrong. TF and TN's actions mark a delta between what happened with the student and what should have happened, but they do not provide descriptions of how that normative condition should have appeared.

Implications. One possible implication of this dimension is that students have to focus on different aspects of failure. In the cases of students receiving descriptions of the normative action, students instantly know what action they are expected to produce. The focus of the failure response process can then turn toward understanding the causes of the obstacle and figuring out

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how to deploy the normative action. In contrast, the latter cases in which tutors withhold a description of the resolution to the obstacle make it so that participants have to figure out what would be entailed in correcting the mistake. The failure response process is defined in strong terms by the students' need to participate in the discovery of the resolution to the obstacle.

In contrast to the four exchanges above, in the following three exchanges, the student, not the tutor, draws initial attention to an obstacle. SF2 and SU publicly articulate not knowing how to proceed on a math problem (Figures 23 and 24), and SD publicly articulates feeling uncertain about a math action he produced on a problem (Figure 25).

MINUS SIGN CASE

Figure 23: SF2 asks TO for help and SF2 confirms which problem (without providing a correction).

Figure 24: SU explains that she's confused and needs help and TK clarifies which problem SU needs help with (without providing a correction).

DRAWING FRACTIONS CASE

TC: You have to make it look like this (.) right?

TC points to image in example problem

Ex) $\frac{2}{7} \times \frac{1}{4} = \frac{2}{28}$ 1) $\frac{1}{4} \times \frac{4}{7} =$

SD: ↑Oh (.) yeah- but (.) an:d you do twenty-nine like (2.0) down?

SD gestures four consecutive downward thrusts with his left hand above the example.

Ex) $\frac{2}{7} \times \frac{1}{4} = \frac{2}{28}$
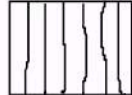
TC: Okay:

SD: One (1.0) two (1.0) three (1.0) four (0.8) five (0.8). Wait do you:?

1) $\frac{1}{4} \times \frac{4}{7} =$

SD draws six vertical lines

SD looks up at TC

TC: Wait. (1.0) °No.°

Figure 25: SD proposes an idea to solve the math problem, implements it, doubts his approach, and then TC agrees that the approach is wrong (without providing a correction).

Recognizing the obstacle

In the minus sign and division cases (SF2 and SU), the students recognize and publicly state the presence of an obstacle. SF2 announces that he has reached an obstacle by asking for help ("Can you help me?") and SU announces that she has reached an obstacle by stating that she is confused and needs help ("I need help on this one"). The subsequent turns in the conversation clarify what problem on the homework assignment gave the students trouble (1/3 – 4/9 and 28 ÷ 4). In this way, the students initially flag the obstacle, and the tutors together with the students provide descriptions of that obstacle (TO's "One-third minus four ninths?" and TK's "So twenty-eight divided by four?").

In the drawing fractions exchange, SD begins to work through the problem and proposes an idea for how to solve it. He starts to implement the approach and then interrupts his own action to ask TC if his approach is what he should be doing. TC agrees with SD's hesitation ("Wait. No.") and immediately launches an inquiry into what they could do differently (not transcribed). In this exchange, the student's hesitation and the tutor's affirmation signal that they are grappling with the question of whether or not this math problem is an obstacle.

Guiding toward the solution

The accounts of the obstacles facing SF2 and SU include no initial guidance over how to achieve a correct solution to these problems. In other words, the tutors provide no insight yet into what set of mathematical actions should take place in order for these students to continue making progress toward the goal of achieving complete and accurate homework. The interaction, apart from restating the mathematical obstacle, has not in any sense provided contours for how to arrive at the normative solution. The account of the obstacle facing SD is similarly devoid of

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contours for how to arrive at the math actions that will move the student toward the correct answer.

 Implications. As noted in the first four exchanges, one possible implication of providing no immediate guidance toward the normative action is that students and tutors need to focus attention on resolving the obstacle. Leaving the resolution unknown from the start means that the process of discovering it will take place publicly between participants. It sets up an activity in which participants will collaborate to unfold the normative action, even if that activity comes at the cost of a careful search for the causes of the obstacle. In contrast, with a swift correction up front (as we saw in the laughter and addition cases), the process used to figure out the normative action takes place privately.

Timing

Looking across all seven dyads, we can track the time that elapses between the obstacle and the recognition of the obstacle. In the first three exchanges above, the tutors flag the obstacles simultaneous with or just after the obstacles arise. TF catches the math error ($5 + 4 = 8$) about a half second after SZ publicly states the incorrect number. TM and TF both intercept their students' obstacles (laughter and missing the reciprocal) at the same time that the obstacles arise, in the former case while the student is still laughing and in the latter case while the student is in the process of skipping a necessary step in division of fractions. Similarly, SF and SD both flag the obstacle a moment after its occurrence. SF has barely finished writing the problem when he requests help, and SD is caught in the middle of working out an attempt to solve the problem when he second-guesses his approach and solicits the tutor's assessment.

Because all of the tutors had been attentive to their students' actions leading up to the obstacle, the timing through which they recognize the disruption draws attention to the students' recent or current actions. In the reciprocal case, even TF's non-specific "hold-on" draws attention to the possible problem of SJ drawing an oval around the numerator of one fraction and the denominator of the other. In other words, the timing between the tutor's utterance and student's physical action draws specific attention to an obstacle in a way that betrays the lack of precision in language. Even though speech remains ambiguous, the timing of that speech with the student's actions precisely implicates a narrow range of actions as possible obstacles.

TN, in contrast, catches the mistake 3 minutes and 3 seconds after it takes place. Instead of operating within the activity that gave rise to the disruption, TN and SG have to reflect back on events that happened in the distant past (distant relative to the other three exchanges). TN's verbal statement about the obstacle, "Do you want to look 'em over with me," indexes her recently completed action of checking SG's homework. SG can know that the obstacle lies somewhere on his homework page, but because TN times her comment with the completion of checking homework, she does not precisely implicate a certain moment on SG's work. Similarly, SU had been sitting and talking with a friend for 19 seconds before TK walks up and asks what number she is working on, after which SU reports that she is confused. The delay means that the conditions that gave rise to SU's inaction on the problem are unavailable to the tutor. Instead of working with the public practices that preceded the obstacle, both SG/TN and SU/TK have to work with what is available in writing on the homework and what they can recall in memory about the events that preceded the obstacle.

Implications. Whether the participants notice the disruption immediately or after a delay has implications for what resources the participants can use to correct the mistake—a topic

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discussed in depth in subsequent sections. For now, we can note that as the delay lengthens, this places a larger burden on memory to recall the events that preceded the obstacle and the events that occurred simultaneous with the obstacle, which could constrain the attribution search process. Moreover, depending on the amount of subsequent work that builds on the obstacle, participants may have more to revise the longer the delay persists. Finally, factors such as student confidence and flow in activity, in addition to where students devote attention to best support learning, may all be dynamically related to the amount of time that elapses between the point that someone notices the obstacle and the point that someone publicly addresses the obstacle.

Past effort versus inaction

Looking across all seven dyads, we can focus on the last dimension of the obstacle recognition process: whether or not students have publicly attempted the obstacle. For SZ, SF, SJ, SG, and SD, their tutors' utterances—"nine," "shhhh," "hold on," "do you want to look 'em over with me?" and "wait"—refer to the actions the students have completed or are in the process of completing. The tutors and students are reflecting on failure in the past public actions that the student performed. In contrast, SF2 in the minus sign case and SU in the division case have not publicly attempted to solve the math problem to which they call attention as an obstacle—"Can you help me?" and "I need help on this one." The process of finding the obstacle does not rely on the public actions of the student struggling to overcome it.

     Implications. There are a few possible implications of students constituting inaction toward a future math problem as an obstacle. Instead of labeling a past concrete action as an obstacle, SF2 and SU label the possibility of failure as an obstacle. They have yet to attempt the

problem. That the tutors recognize these as valid moments of failure—and not, for example, occasions where students need to make a first attempt—makes a statement about the minimal amount of work needed before students can solicit help. Can students pause ahead of a problem and solicit help, or would students first need to make an effort, both to check their independent skill on the problem and inform the search for causes and interventions? Moving forward without a prior public attempt to resolve the obstacle will mean that participants have to speculate about what caused the student to classify the math problem as an obstacle without having information about what the student could have managed on his/her own. Watching or experiencing a public attempt offers no guarantee that the participants will then comprehensively understand the causes of the failure or design a productive and sustainable intervention, but it bears reflection to consider what information participants would gain from viewing a first attempt.

5.2   Summary of Process 1: Obstacle recognition

To summarize the obstacle recognition process, *tutors, students,* or *both participants* can take action to publicly acknowledge the presence of an obstacle. The tutors found the obstacles in the laughter (SF/TM), addition (SZ/TC), reciprocal (SJ/TF), and missing zero (SG/TN) cases. The students initially found obstacles in the minus sign (SF2/TO), division (SU/TK), and drawing fractions (SD/TC) episodes.

Participants can flag students' prior public actions as obstacles or students' non-actions as obstacles. SZ, SF1, SJ, SG and SD all produce actions that participants say should be corrected. How the students added up numbers, laughed audibly, performed steps in division of fractions, multiplied two digit numbers, and drew multiplication of fractions were all construed as actions that, if meant to realize the goal of quickly achieving complete and accurate homework, needed to be performed differently—adding numbers correctly, remaining silent, taking the reciprocal,

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including all place values, and drawing fractions properly. SF2 and SU, in contrast, flag obstacles around which they have taken no public action.

The failure recognition process, even in this early stage, involves participants labeling the characteristics of the obstacle with different amounts of precision. SZ and SF1 know the exact obstacle, SJ and SD know that the obstacle is located somewhere in their recent actions, SG knows that the obstacle is located somewhere on the entire first page of his math homework, and SF2 and SU know the exact obstacle that lies ahead of them. Looking across these cases, we see a spectrum of granularity in how precisely the obstacle is labeled: *this exact* prior action was an obstacle, *some very recent* prior actions were obstacles, *some action that occurred during the previous ten minutes of working on homework* was an obstacle, and *this exact problem not yet publicly attempted* is an obstacle.

From the start of the process of recognizing the obstacle, participants offer different types of guidelines for how to solve the problem. In the laughter and addition cases, the tutors state what action the students should take in the very same act of recognizing the obstacle. The students in these exchanges, SZ and SF1, know both the obstacle and the resolution. All five of the other participants during the failure recognition process are given no indication yet of how to route around the obstacle.

Lastly, there is the factor of how much time elapses between the non-normative action and the recognition of the action as an obstacle. SZ, SF1, SJ, SD, and SF2 all recognize the obstacle seconds after the students produce the non-normative action or seconds after the student reports not knowing how to proceed. SU, in contrast, reports not knowing how to proceed 19 seconds after stopping working. Even further removed from the non-normative action, SG and his tutor recognize SG's math miscalculation 3 minutes and 3 seconds after it occurs.

The choices participants make in the obstacle recognition process could influence norms around who has agency and skill to find failure, what counts as failure, how much work students need to attempt before something counts as failure, what the participants focus on together after failure, what can be recalled about the conditions prior to the failure, how much subsequent work building on the obstacle needs to be corrected, and how much participants need to speculate on the causes of failure (see Figure 26). I will return to these implications in the discussion section of this chapter. For now, this analysis sets the stage for the subsequent discussion of the causal search and intervention processes.
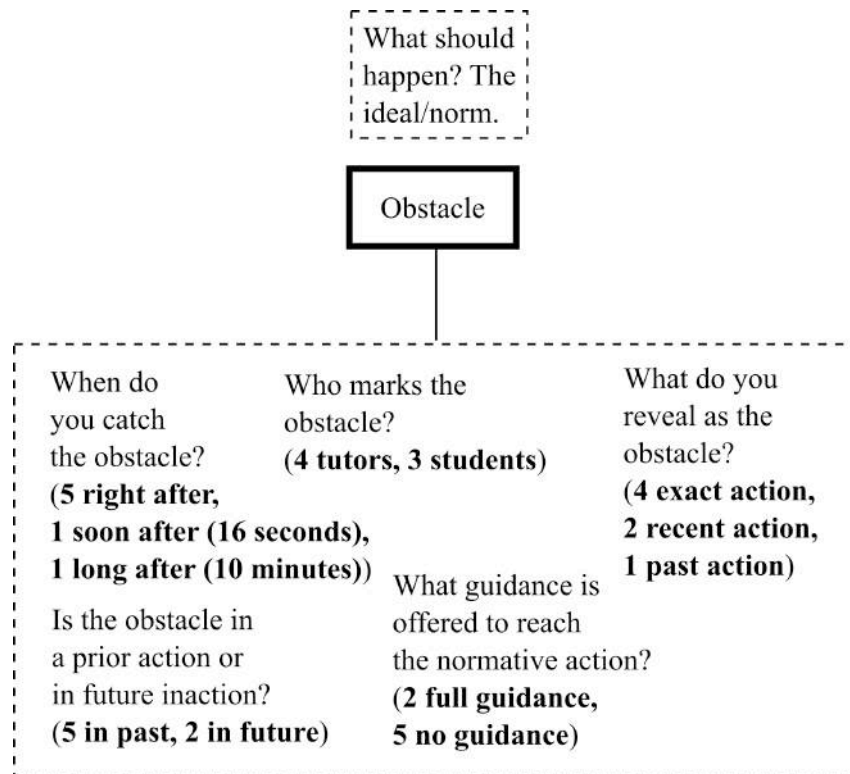
Figure 26: The recognition of an obstacle immediately demonstrates that something different from a past action or something unknown should happen. The recognition process encompasses each of the five dimensions in the dotted rectangle below the obstacle and the numbers in parentheses reference the frequency of events across seven dyads.

5.3 Process 2: Causal search

Participants have opportunities in conversation to publicly state what they attribute to obstacles—in other words, what caused the obstacles to arise. We will see three instances in which participants state that they are stuck (or do not know what to do next) because they are temporarily confused and one instance in which a student states that he is stuck because of low skill level. We will also see participants state that they made a past mistake because of increased difficulty, confusion, too much speed, and another student's distracting actions. In all of these cases, participants implicitly answer the question, "Why did this obstacle come about?" Phrased in affirmative language, participants are saying, "I am stuck (or I made a mistake) because of some factor."

I make four observations regarding the public search for causes of obstacles: (1) causes are explicitly stated; (2) causes of causes can be proposed; (3) participants can locate causes within themselves, another person, or the environment; and (4) the public discussion of causes occurs at different points in the failure interaction process.

The first four exchanges that I analyze all contain instances of participants blaming the cognitive state of confusion for the occurrence of the obstacle. In these exchanges, confusion itself is not pinned as the obstacle; the obstacle is a math problem that inhibits progress on math homework. It is because students become confused (not because they have a dull pencil, lost something to memory, became distracted, etc.) that they cannot make progress on math homework. In the first transcript below (Figure 27), SU explains to TK that she is confused and needs help on a problem she has not attempted. In the second and third transcripts, SZ explains that her past mistake resulted from confusion (Figure 28), whereas TC explains that SZ's past mistake resulted from too much speed (Figure 29).

SU notices TK approaching

TK: Wh- what problem are we on.
    (1.5)
SU: I'm [con] fu:

28 ÷ 4
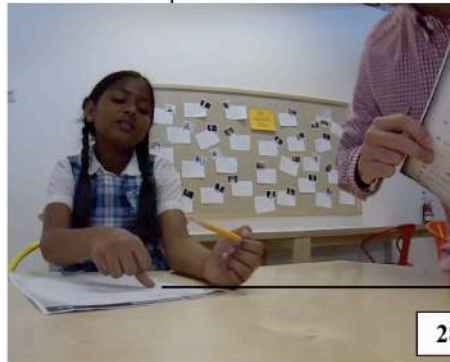
SU touches problem with thumb.

TK: Huh?
SU: I need help on thi:s one.
TK: That's fine. So [twenty-eight] divided by four?
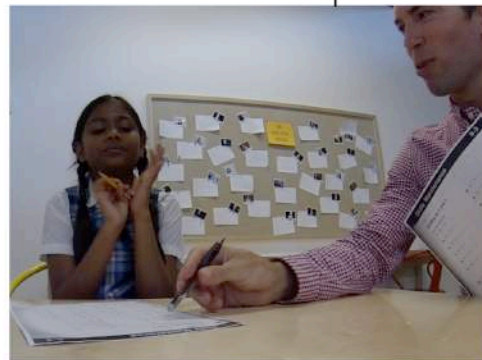
TK points to problem with thumb.

Figure 27: SU attributes her inability to make progress on this problem to her own confusion.

Figure 28: SZ credits her own confusion for causing the miscalculation.

TC: But you need to slow down though
SZ: Okay.
(1.5)
TC: Like this. You're not even done here.

TC points to unfinished math problem.

SZ: (.) Oops. (1.0)

SZ laughs and starts erasing mistake.

TC: [See? (*laughing*)]
SZ: [(*laughing*)   ]

Figure 29: TC credits SZ's speed for causing her to leave an answer unfinished.

Causes. The cognitive state of confusion, in the exchanges between these dyads, is credited for halting SU's progress on her math homework and for leading to SZ's calculation mistake. SU's comment that she is confused can be understood in the context of her lack of action on the problem. Sitting without working—or her own body's inaction—and her vocal

solicitation for assistance ("I need help on this one") are signs that SU has reached a hurdle; the statement that she is confused acts as the attribution for her inaction. In the other dyad, SZ includes the phrase, "that's why," in her statement about confusion, vocally tying the statement about her confusion to the prior obstacle. TC offers an alternative cause of the addition error: speed. TC notes that the speed with which SZ is working through her homework is responsible for her calculation errors, vocally explaining that a past mistake is the outcome of working too quickly ("You need to slow down though…Like this. You're not even done here").

Causes of causes. TK/SU and TC/SZ do not publicly articulate what might be causing the students' states of confusion. In this way, the students' stories about the roots of their failures extend back one step into the past. The students state that they are confused, but not what caused their confusion.

Location of causes. The state of confusion and the pace of work are both understood to be events that occur inside the students, tied grammatically in language to a specific person: "*I'm* confused," "*I* get confused," and "*You* need to slow down" (my italics for emphasis). Because the participants in these cases do not posit causes of causes, the etiology of both obstacles is comprised of factors internal to the students.

Timing of causal search. Finally, these attributions occur at different points in the failure interaction process. SU articulates the reason why she is struggling before she articulates in words what she is struggling with but simultaneous with locating in gesture the part in the environment that is giving her trouble. She also articulates the reason for her struggle before attempting publicly to solve the problem. In contrast, SZ has already made a calculation error and TC has flagged and corrected the error before SZ states that she gets confused on these problems. The former acts as a reason for soliciting help on a coming challenge while the latter

acts as an account for a prior mistake. In this way, attributions of failure may serve different purposes depending on how far along students are in attempting, locating, and correcting an obstacle.

In the next two exchanges, participants again blame confusion for the students' struggles, but they add causes to their stories, ones that explain how the confusion arose. In the minus sign case, TO blames a negative number for causing the confusion (Figure 30). In the drawing fractions case, SD blames TC for causing the confusion (Figure 31). Both of these moves shift the ascription that is at the beginning of the causal chain from an internal to an external space. As noted earlier, a series of events happen before the drawing fractions transcript: TC and SD consider looking at a textbook, observe the problem together, and try to recall what happened in class. These have been left out of the transcript because they are prohibitively long.

SF2: But I don't get it. (1.0)
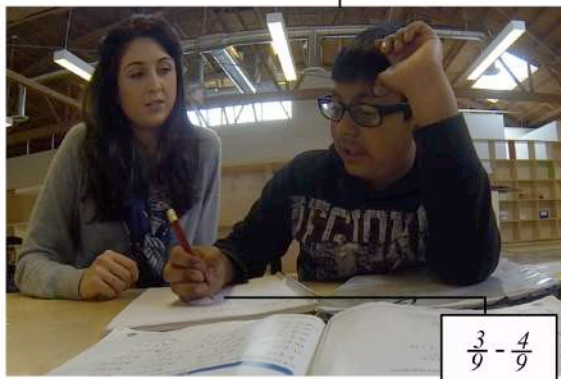
SF2 hovers pencil back and forth over problem.

(3.0)

TO leans in to look at problem.

TO: Okay (1.0). Um: because it's a negative.

TO points to negative sign.

TO: (.) Is that what was confu:sing?

SF2: Yeah.

Figure 30: TO proposes that SF2 is stuck because a negative sign caused him to be confused.

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TC: You don't remember it in class?
   (0.5)
SD: ⌐No::¬ (1.0) I su:ck at th[i:::s.   ]
TC: [Well ↑no. You don't.]

SD looks off to side and taps pencil on desk.

TC: You just. (2.5) We don't suck at it. I'm trying to-
   I'm trying to figure this out too.
   (0.5)
SD: (*click sound*) You're making it confu:sed.
TC: ⌐Wha:t?¬

*TC asks the question and leans back while
SD begins to draw on his calendar.*

SD: º[You're making me confu:sed.º   ]
TC: [Okay you know what? You know what we should do.]
   Check it out.

Figure 31: SD blames his own inability, TC blames "trying to figure this out," and SD then blames the tutor for causing confusion.

Causes. After SF2 reports and points to the obstacle—which is a problem involving fraction subtraction—TO looks at the problem and flags the subtraction sign ("because it's a negative") as the cause of the confusion ("Is that what was confusing?"). In this way, TO proposes a story in which a negative sign causes confusion that in turn causes inability in the student to make progress on homework. Similarly, SD blames the struggle on his own lack of

skill ("I suck at this") and on TC creating confusion ("You're making it confused" and "You're making me confused"). In this way, SD proposes a story in which his own lack of skill and his tutor's actions, the latter of which make him confused, are jointly responsible for his struggle to solve this math problem. Whereas the causes of confusion in SU and SZ (the students discussed earlier in this section) were never publicly discussed, both TO and SD assert causes of their own confusion: a subtraction sign and a tutor.

Location of causes. Where are these causes located? When participants propose chains of causes, the locus of the causes can be distributed across people and the environment. The negative sign to which TO deictically points is located in the external world of the lined notebook paper but the confusion is internal to SF2. The tutor's mention of the external negative sign, coupled with her mention of the confusion in the student, shows the deep connection between external and internal spaces. The negative sign does not stand alone as an isolated cause. TO denotes that it deserves blame because it causes confusion in the student. Both spaces are implicated in the cause of the obstacle.

In the drawing fractions episode, the actions that TC produces create in SD a state of confusion. Tellingly, SD says, "You're making *it* confused. You're making *me* confused," (my italics) changing the word "it" to "me" in his consecutive phrases about confusion, migrating the state of confusion from the general activity to his own experience. The participants, in this way, credit inscriptions in the environment, other people, and their own cognitive states as conditions responsible for creating the inability to make progress on math homework. The locus of these causes is distributed across the environment and the student in one case (SF2/TO) and across the tutor and student in the other case (SD/TC).

Timing of causal search. How are these attributions positioned in the failure interaction process? In the minus sign episode, SF2 has not yet attempted to publicly solve the problem. This means that his tutor, TO, searches for the cause of the obstacle without information about what SF2 would have been able to accomplish on his own. TO formulates a guess about what might be behind SF2's lack of understanding ("because it's a negative"). SF2 verifies that TO is correct ("yeah") in attributing his confusion to the negative sign. In contrast, in the drawing fractions case, SD and TC have attempted a wave of actions to solve the math problem, including having SD work on his own, considering using a textbook, looking together, and trying to recall in memory what happened in class. (These moments happened before the transcript above.) It is after this succession of actions that SD blames his own lack of skill and then TC for making him confused.

By the time SD proposes these attributions, he can reflect on what happened during his and TC's earlier attempts. TO, in contrast, needs to provide an attribution without seeing SF2 make a public attempt. Importantly, in both cases, participants are guessing at what might be causing the struggle—even if the participants departs from a position of seeing past attempts, they would still not have perfect knowledge about what caused the obstacle. The difference between the past and future versions is that the participants are working with different amounts of information about why the barrier appeared.

Moving on to the next exchange, we find that TM and SF, after publicly acknowledging that SF should not be laughing and should instead be focusing on his homework, discuss a cause of the initial laughter and distraction: a peer sitting across the table eating a mango in an apparently comical way (Figure 32).

TM: Okay (1.0) I need you to focus. Okay?

TM taps the math problem 3 times and leaves her finger touching the page

TM: Don't get distracted.

TM points over her shoulder

SF: I know but he- (.) [He has] a [mango >it's like<]
TM: [There's]   [There's still   ]

TM taps SF's bicep
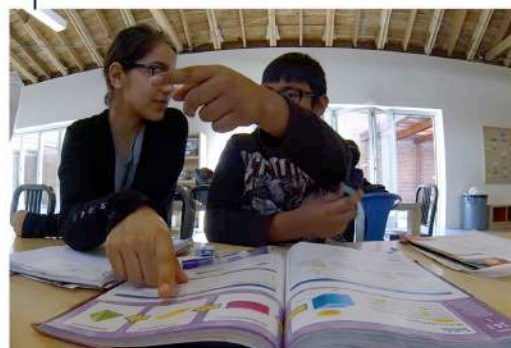
TM repeatedly taps math textbook page while SF holds his point toward the student with the mango.

TM: But there's [still]
SF: [He] has a mango in this=
TM: =Yeah. I know. It's pretty funny.

Figure 32: As TM is encouraging SF to focus, SF credits a friend with a mango for causing his continued laughter.

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Causes. In the above exchange, SF acknowledges that he should be focused ("I know") but then provides a reason for why he can't focus ("but he has a mango"), explaining that the person sitting across the table from him is doing something with a mango that triggered his own laughter. As before, the verbal description of the cause is understood in the context of SF's continued physical signs of laughter. In this way, SF proposes a story in which the friend with the mango causes him to laugh and lose focus on his homework. SF's "but" in "but he has a mango" connects the event of continued laughter (the obstacle) to the friend with the mango (the cause).

Location of causes. The locus of the cause, as in the earlier drawing fractions case of SD blaming TC for causing confusion, can be found in someone other than the student. In the same way that SD positioned TC as causing confusion, here SF positions the student with the mango as causing his own laughter/distraction. In the last line of the transcript, TM acknowledges the validity of the causal link between the external mango and the student's internal experience of laughter ("It's pretty funny").

Timing of causal search. How is the attribution process positioned temporally in the course of the failure interaction? The search for the etiology of the obstacle takes place after the non-normative action has publicly transpired (SF's laughter) and after participants recognize that a different action should be taking place ("Shhh" and "I need you to focus"). In contrast to when SF2 and TO in the minus sign case pause before the obstacle and posit what the reason might be for inability to move forward, here SF and TM reflect back on the conditions that gave rise to past (and continuing) laughter.

The final exchange, between SJ and TF, presents a situation in which it is not altogether clear whether TF describes a cause of the obstacle or the intensity of the obstacle (Figure 33).

TF: Follow your steps again.

SJ looks down at her work.

(9.5)

SJ: It's r:ight. (3.0) Cuz three goes into three once and three goes into thirty-three eleven. (4.0)

SJ looks up at TF and they continue to look at each other without talking.

SJ: (*laughing*) Why are you looking at [me like tha::   ]
TF: [>alright alright alright<]

SJ smiles and laughs and TF smiles and leans back

TF: So it got hard, right? (0.8) It got hard?
SJ: Yeah: (*smiling*)

Figure 33: TF's remark, "it got hard," may signal an attribution of this math problem being difficult or it may signal the intensity of their current obstacle.

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In their conversation, SJ attempts to correct the problem that TF had flagged earlier, and when she does not succeed, TF asks a question about the difficulty of the work. The obstacle in this exchange is a missed step on a division of fractions problem, and when TF does not accept SJ's argument that the work is correct, there is a long pause, some laughter, and then TF's question: "So it got hard, right? It got hard?" These two questions can be plausibly interpreted in two ways. The first, which would not be an attribution, is a description of the present obstacle. This is akin to stating that the two participants are in a state of math struggle—things are simply hard right now. If this is the case, TF's phrase is a reinforcement of the fact that the student is experiencing an obstacle, and this would in no way point to what is causing the failure moment. The other interpretation, which *would* be an attribution, is to see TF crediting the struggle to a difficult math problem. SJ is working on the very last problem on the assignment. Does TF mean to suggest that the level of difficulty increased, such that the problems finally "got hard," and SJ can't overcome the difficulty of that external obstacle? We would expect this type of attribution to be common in a math community, but without a way to disambiguate TF's question, I cannot with any confidence argue that these participants attributed the struggle to the difficulty of the math problem.

5.4 Summary of process 2: Causal search

I made four observations about the causal search process in each of the six exchanges above (the seventh exchange between SG and TN did not in any way involve an attribution of failure): (1) Causes are explicitly stated; (2) Causes of causes can be stated; (3) Participants can locate causes within themselves, another person, or the environment; and (4) The public discussion of causes occurs at different points in the failure interaction process (see Figure 34).
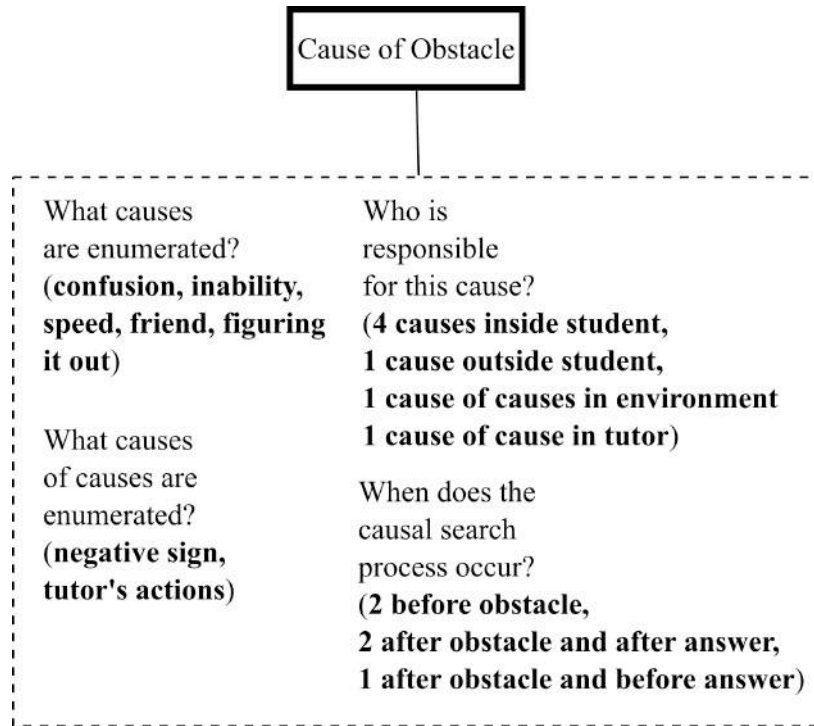
Figure 34: The search for causes of an obstacle encompasses each of the four dimensions in the dotted rectangle and the numbers in parentheses reference the frequency of events across the five dyads who definitively provided attributions of failure.

To summarize across all six exchanges, we found that participants blamed confusion, working too quickly, a negative sign, a friend and his mango, and being bad at this math problem (including, speculatively, the increased difficulty of the math problem). Each fits the following pattern: The reason I am experiencing this obstacle (whether a past non-normative action or uncertainty about how to act going forward) is because of some event(s). In one case, the tutor and the student disagreed about the cause of the obstacle (speed or confusion), and in another case, the same student provided two consecutive but different accounts of the cause of the obstacle (lack of skill and the tutor creating confusion). In two cases (SD/TC and SF2/TO), participants articulated a chain of events as the cause of the obstacle. These exchanges document the potential to extend the reach of the causal search process even further into the past. For example, the cognitive state of confusion that gives rise to the inability to proceed on math homework can itself be caused by specific circumstances.

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These attributions of failure locate the cause(s) in some part of the distributed activity system of the homework activity, which carries important implications for the intervention stage. The locus dimension tracks to some extent who or what is responsible for the presence of the cause. The four conversations about confusion positioned the experience of confusion inside the student, and yet two positioned that confusion as emerging out of experiences external to the student (a math sign on the page and the tutor). The discussion about the friend with the mango (and the difficult math problem, if we grant that an attribution) equally positions the cause beyond the skin of the student. The phrase, "I suck at this," locates a lack of capacity inside the student (with the pronoun "I") as responsible for the student's continued struggle. In this way, these six exchanges depict causes as individuated internal experiences and as connected across internal and external experience.

Finally, the timing with which participants posit causes of obstacles varies across the six exchanges. In two cases, the causal search process takes place after participants locate the obstacle and after participants know what normative action they should take to move forward. In two cases, the causal search process takes place after the students have publicly grappled with the obstacle but before the students know what the normative action should be. In two cases, the causal search process takes place before the students have publicly attempted to overcome the obstacle. I address interconnections between the causal search and the other two failure response processes in the discussion section of this chapter.

5.5   Process 3: Intervention

The construction and attribution processes discussed in the prior sections dealt with recognizing *present* obstacles and *past* causes. The intervention process focuses on the *future*—what needs to be done for students to get back on track, avoid making the mistake again, learn something about

the math problem, etc. The intervention guides the student toward an action that has not yet happened and which will move the student closer toward the goal of finishing homework.

I make three points in this section: Interventions (1) focus either on events that happened in the past or on new actions that can take place in the future; (2) involve a division of labor in which the students control some actions and the tutors control some actions; (3) they tell a story about what actions are believed to be needed to route around the present or upcoming obstacle.

In the following two exchanges, TO/SF2 (Figure 35) and TK/SU (Figure 36) both focus on new actions that the students have not attempted in the past, drawing attention to a digit that can be subtracted from another digit and drawing attention to two division strategies. Both interventions do not attempt to correct past inaccuracies in the students' math actions; they depart from a point where the students suspended their work.

TO: (.) Is that what was confu:sing?
SF2: Yeah.
TO: Okay so- what's three minus four?

TO points to problem and looks at SF2
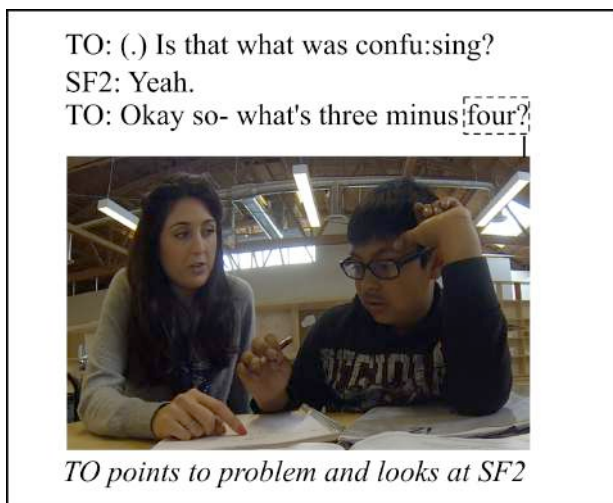
Figure 35: TO intervenes by describing a calculation and giving SF2 the chance to respond.

TK: That's fine. So twenty-eight divided by four?

TK points to problem with thumb.

SU: (*nods*)
TK: Okay, so let's think about it. So there's a couple ways to approach it right?

SU and TK look at each other.
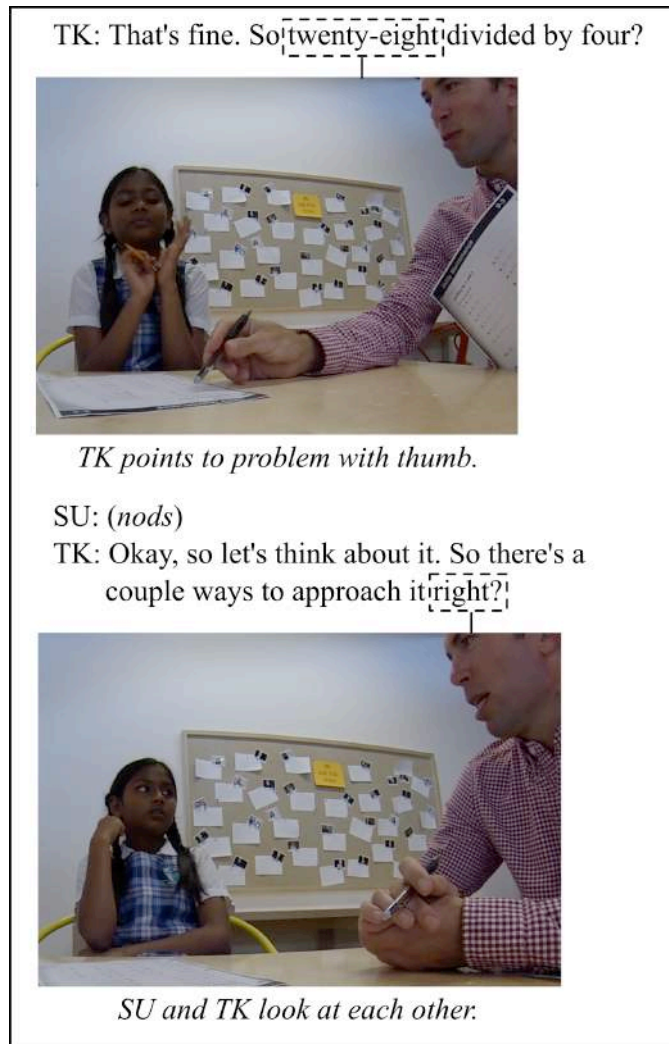
Figure 36: TK talks about how there are a few ways to approach the math problem.

Target of the intervention. In the two exchanges above, SF2/TO and SU/TK both focus on actions that the students have not yet publicly attempted. TO's question about three minus four and TK's question about strategies for approaching the problem both invoke discussions about aspects of the math problem that neither student has attempted publicly leading up to this moment. In this way, the interventions are geared toward novel actions that can move the students toward the goal of finishing homework.

Division of labor in the intervention. On the issue of controllability, TO picks out the two numbers that should be subtracted and voices them aloud as a question for the student, pausing to

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give SF2 control over how to answer the question. The intervention parses the action that's needed (3 – 4 = -1) into separate parts. The tutor handles all of the steps involved in formulating 3 – 4 and the student is given the chance to handle the solution (what 3 – 4 equals). TO scaffolds the intervention, suggesting that the student cannot control which numbers to select and in what order to subtract them, but that the student can control the answer to the subtraction problem. From a narrative standpoint, these actions signal that the student has some agency to resolve the cause of the obstacle, but needs assistance.

TK begins the process of routing around SU's trouble spot with a meta-level discussion about different strategies for solving the math problem. The labor for the activity is divided, with TK framing the problem as having two possible approaches and giving the student the first chance to suggest approaches in the coming turns. Looking across these two dimensions, we have interventions that focus on novel actions, some parts of which the tutors enact and other parts of which the students are given agency to control.

Content of the intervention. Because interventions are designed to move the students closer to their goals, they carry strong connotations about what experiences the students need to route around the present obstacle. TO, for example, in focusing the conversation on a question about three minus four, creates an intervention that suggests that SF2 needs knowledge about what numbers to subtract in order to overcome his present state of confusion. Similarly, in proposing a discussion about two types of approaches to the math division problem, TK creates an intervention that suggests that SU needs strategy knowledge to overcome her own present state of confusion. Both interventions target gaps in math knowledge, suggesting that math ideas are needed to resolve the cause of the obstacle (in these cases, confusion) and to return to making

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progress on the math assignment. From a narrative standpoint, the content of the intervention signals what actions are used to stamp out the cause of the obstacle.

The following two exchanges (TF/SJ and TN/SG), in contrast, involve tutors drawing attention to non-normative math actions students have made in the past and building the intervention in part out of the earlier math work students accomplished (Figures 37 and 38).

TF: We're gonna- what are we gonna do?
(3.0)

*SJ lifts up her workbook and moves it in front
of her body.*

SJ: Stop?

TF: Okay, pause, right? Let's work on this together, okay?
So something's wrong here.

TF places flat hand covering SJ's work on problem.

TF: Yeah (*directed to other student*). Something's wrong here,
right? Right?

SF: (*nodding but looking away*) (3.5)

TF: So we gotta- we gotta find out what it is. So let's start
from the beginning, okay?

SJ: Uh huh

TF: So this is the beginning?
(1.0)

SJ: (*nods*).

TF: So you did this. So: four times eight is thirty-two.

SJ: (*nods*)

TF: Plus one is thirty-three. So that's right. Three times three is
nine plus- plus two is eleven over three that's right. Okay so
these are ri:ght. So then you went to he:re. So what
happened here?

TF points to 11/3.

Figure 37: TF walks SJ to the point where she made a mistake and asks what happened.

TN is checking SF's completed homework, using her finger to point to each question.

(24.0)

TN: Okay. (6.0) Do you want to look 'em over with me.
       (1.0)
TN: So one twenty twenty thirty eighty eighty sixty
   seventy twenty eighty eighty seve::n.
   (1.5)

TN, who has been pointing to each value she names, pauses her finger at 7 and looks up at SF.

SF: >Oh wait. Seventy::.<

Figure 38: TN points to answers to past problems and pauses at one where SG has produced an incorrect answer.

Target of the intervention. Whereas the first two interventions examined in this section (SU/TK and SF2/TO) focused on actions not yet performed in public, the exchanges between SJ/TF and SG/TN are embedded in the students' prior work. Referencing the pencil markings students made previously while working through the problem, the tutors can focus attention on

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the students' past actions, recreating for a brief moment an aspect of the students' prior thinking. TF starts at the beginning of the problem and looks at all the written steps SJ has taken, endorsing the correct moves she made. In focusing on the pencil marking on the page, the intervention gears attention only toward SJ's mathematical actions that ended up on paper. The math actions conducted in working memory, imagination, or speech, which accompanied the written numbers, are ignored in the intervention. In addition, the non-mathematical actions, such as talking with a neighbor, yawning, or feeling bored or urgent, that may have accompanied the prior mathematical actions of solving the problem are not reprised or re-experienced in this intervention. TN, in a similar way, focuses attention on the culminating, written solutions to TN's work on the double-digit division problems. TN highlights all of the solutions that TN produced, one after the other, and pauses at the moment in the past where TN made a mistake. The intervention does not highlight the thinking that SG orchestrated to get to the point of writing down a solution.

Division of labor in the intervention. The division of labor is handled similarly in the two exchanges. Both TF and TN re-voice aspects of the students' prior written work, interleaving their own speech with the student's prior written math actions as they endorse the accuracy of the past work. Whereas TF explicitly states which actions are "right," TN endorses SG's prior answers by reading through his correct answers quickly. Both tutors pause at the moment where their students made a prior mistake, giving the students the opportunity to re-enter or re-experience the moment just before the mistake. In handing the floor back to the students at that moment, the tutors have engineered an intervention where the students can see precisely where they made an error and then search for the mathematical action they should have made.

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Content of the intervention. Both interventions are oriented toward dealing with the present obstacle, which at this point in time, the students have yet to overcome. Whereas the interventions in the first two exchanges suggested that the students needed mathematical ideas to overcome the obstacle, these two exchanges suggest that students need to revisit the problem—they don't need new ideas, just another chance. In focusing attention at the exact moment on the assignment where a mistake was made and then handing the floor to the student, the intervention assumes the students have the mathematical resources to repair the mistake once they know where to look. Neither intervention provides the students with resources to correct the mistake once the students know where the mistake can be found; the students are expected to see the fault in their prior work and generate the self-correction.

In the next exchange, between SZ and TC, the intervention immediately corrects the obstacle and then focuses on how to avoid upcoming obstacles, an example of an intervention designed explicitly for expected future obstacles (Figure 39).

SZ: Five plus four is <u>eight.</u> (.) Z[ero] plus
TC: [nine]

TC: Five plus four is <u>nine.</u>
SZ: Oh↑yeah I get confused that's why.
(0.5)

SZ starts to erase problem, TC starts to smile
SZ: That's [nine   ]
TC: [>You gotta] slow down.<
           (4.0) <°You gotta slow down.°>

Figure 39: TC tells SZ that she needs to slow down.

The intervention in the exchange between TC and SZ focuses on two events. TC immediately corrects SZ's miscalculation and then asks her to slow down. The first correction does not focus on SZ's past strategy or a future strategy—the verbal statement, "nine," simply takes SZ to the mathematically correct end state for that calculation. The tutor allows the student to control no aspect of the intervention, and the intervention is focused on the present obstacle.

Target of the intervention. The second event on which the intervention focuses attention is speed. This occurs through TC's utterance, "You gotta slow down," repeated twice. In the same way that TO and TK introduce new mathematical strategies into the intervention, TC introduces a new plan for the pace with which SZ should work through her homework—slowing down. The intervention focuses on a future action without asking SZ to solve the problem again at a slower speed.

Division of labor in the intervention. The labor is divided between the originator of the plan (the tutor) and the person expected to deploy the plan (the student), in the same way that the interventions I examined earlier in this section were divided between the tutor (TO) who selected a number to subtract from another number and the student (SF2) who was expected to provide a solution.

Content of the intervention. The suggestion to slow down focuses on an action intended to stave off future obstacles. SZ has already resolved the obstacle that launched the exchange— the tutor corrected the mistake immediately. Expanding the intervention to focus on speed marks a focus on avoiding these types of mistakes on the rest of the assignment. The intervention suggests that SZ needs to slow down to avoid encountering new obstacles on her math homework.

The following exchange, between TM and SF, marks the first example of coercion in the intervention process, an attempt to use a small threat to motivate the normative action (Figure 40).

TM: Do you want me to add time to your reading?

TM asks a question while SF laughs hysterically.
(0.5)
SF: No.

SF pauses laughing and looks at TM.

Figure 40: TM asks a question about adding more time to reading and SF stops laughing.

Target of the intervention. TM attempts a series of interventions in response to SF's laughter. From the prior transcript (Figure 32), TM states: "I need you to focus" and "Don't get distracted." And in the above transcript (Figure 40), TM asks, "Do you want me to add time to your reading?" These three turns implement approaches to moving TM past the obstacle of distracting laughter and toward the normative action of focusing on math homework. All of TM's interventions focus on a future action that has not yet happened—a state of focus—and parallel the exchange examined earlier where TC asks his student to slow down. The intervention

does not look back at what the student experienced in the lead-up to the obstacle. It is focused on changing the state of distraction moving forward, not in understanding how the student could have stopped laughing in the first place.

Division of labor in the intervention. The division of labor of the intervention is organized in such a way that the tutor articulates a desired behavior, and even threatens with a change of plans framed as negative (adding time to reading). The student, in turn, is expected to create a focused state of mind. This parallels the earlier process in the minus sign and division cases in which the tutor suggests a course of action and the student executes all or a part of that action.

Content of the intervention. Finally, the intervention suggests that SF needs to be reminded, told, or coerced into focusing in order to arrive at the point where he returns to work productively on homework. It is not knowledge or ideas that the student needs, but rather, the threat that the student will have to invest more time in a dispreferred action if he does not return to making progress on his homework. Critically, this intervention communicates that the student has the potential or ability to focus if faced with a costly enough punishment.

In the final exchange, between SD and TC, the participants deploy a strategy not seen in any of the prior six, that of delaying the moment in which the tutor and student will have to confront the obstacle (Figure 41).

SD: [You're making me confu:sed.   ]
TC: [Okay you know what? You know what we should do.]
     Check it out. Why don't we just uh:: (2.0). Why don't
     we multiply ⌐this⌐ first. Do all the problems. We'll do the
     picture later.

TC points to the numerical part of the math problem.

TC: How's that?
SD: Yeah:::

Figure 41: TC proposes to solve the numerical problems and return to the picture later.

After having tried to consult a book, examine the problem, and remember how the teacher explained the problem in class (in parts of the conversation not shown in this transcript)—and then blaming lack of ability and the tutor creating confusion—SD and TC are still struggling to understand how to draw a visual model of fraction multiplication. TC proposes that SD skip the drawing part of each problem and start by solving the numerical values; they'll "do the picture later." The intervention effectively postpones the moment when tutor and student will have to face the obstacle again.

In this way, the intervention focuses not on events in the past or possible actions in the future, but rather, closes down the space and postpones the discussion about what will be done to route around the obstacle. The tutor suggests the plan and publicly provides no description of how the labor will be divided in the future. Finally, the intervention does not suggest what the student needs to overcome the obstacle.

5.6   Summary of process 3: Failure intervention

I have argued that failure interventions involve three dimensions: (1) focusing on events that happened in the past or new future actions; (2) dividing the labor of the intervention; and (3) focusing on what actions are needed to route around the present or future obstacle (see Figure 42). The intervention impacts participants' narratives about failure by determining what actions curb the causes of the obstacle, how tutors and students share the work of enacting those actions, and whether the target of the intervention is a revision to past work or a plan for upcoming work.
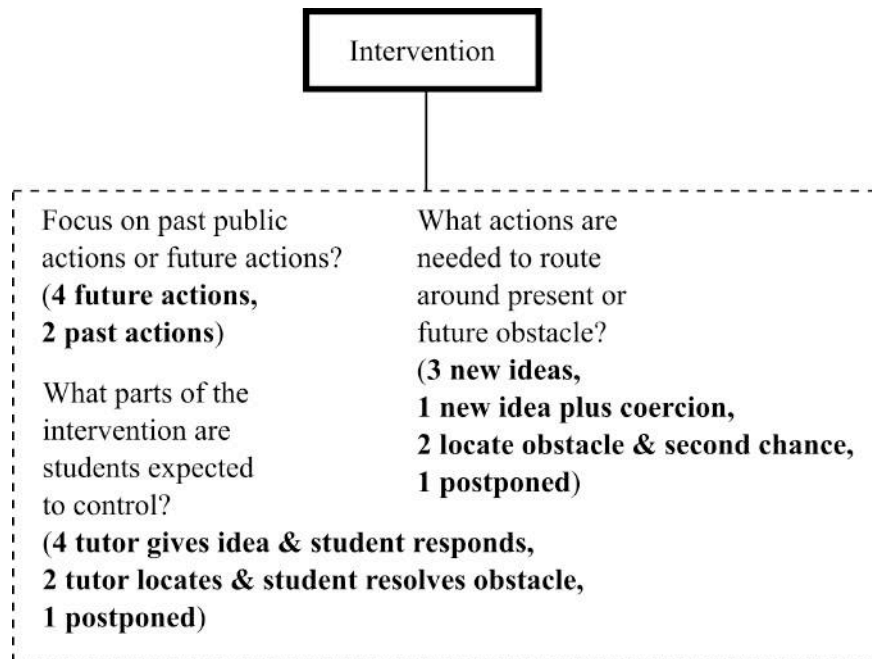
Figure 42: The planning of the intervention encompasses each of the three dimensions in the dotted rectangle and the numbers in parentheses reference the frequency of events across seven dyads.

The first aspect of the failure intervention process involves whether participants draw attention to prior attempts to route around the obstacle (SJ/TF and SG/TN) or whether they highlight new actions (SU/TK, SF2/TO, SZ/TC, and SF/TM). In past-oriented interventions, the students' hand-written markings on the homework page provide a historical context in which the students can investigate how to correct the error. By re-embedding the students in aspects of the

actions that predated the obstacle, the intervention corrects the obstacle by having students recreate their prior effort with some modification. From a narrative standpoint, this means the intervention values learning how to remake a past effort with relevant changes. In future-oriented interventions, participants do not reference how the students worked on the problem beforehand. The participants attempt a new action to arrive at the valued epistemic end without explicitly engaging with the student's prior attempt.

The second aspect of the failure intervention process involves how labor is divided in the set of events recruited to get the student back on course. SJ/TF and SG/TN divide the actions in such a way that the tutors point out the location of a mistake and the students resolve it. The intervention taps into students' existing mathematical resources. In contrast, TM, TC, TO, and TK all introduce new plans of action: start focusing, slow down, subtract two digits, and consider two strategies for dividing numbers, respectively. The students, SF, SZ, SF2, and SU, have agency to execute their tutors' plans. SD and TC, in postponing the moment when they have to face their math obstacle, also postpone the decision over how each party will contribute in the future intervention. This dimension echoes what attribution theorists have described as the controllability of causal ascriptions. How participants divide labor denotes what (parts of the) causes and/or what in the intervention students have agency and skill to control.

The third dimension of the failure intervention process addresses what students need in order to route around a present or future obstacle. TO, TK, and TC design interventions that suggest that SF2, SU, and SZ need new ideas (math actions and a pacing suggestion). TM introduces an idea into the intervention—*cease laughter and start focusing*—but in also imposing a small threat, the intervention denotes that the student needs coercion in addition to the idea of quieting down. TF and TN design interventions that point to locations of prior

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mistakes without introducing new ideas. Finally, TC and SD postpone their search for what they will need to overcome the obstacle. From a narrative standpoint, the intervention denotes whether the participants need new knowledge, a second attempt, motivation, or more time to overcome the obstacle. The intervention selects which (if any) causes of the obstacle are worth targeting and presents a plan for how those causes can be resolved.

5.7   Connections between finding, attributing, and intervening

The above analysis of seven exchanges between tutors and students during math homework presents a new approach to studies of attributions of failure. Instead of documenting the attributions of failure that an individual person contains in his/her mind, and their associated beliefs about the locus, controllability, and stability of those attributions, I have worked to document causal reasoning in response to failure as a context-specific, public practice. How participants navigate the three failure response processes enacts a story about failure, including what participants think failure is, when they should discuss it, what caused it, where the cause is located, what needs to be done to resolve the obstacle, and how much the student should be expected to control in the intervention. In the same way that Ochs et al. (1992) describe storytelling as theory building, these moments of dialogue between tutors and students carve out theories about the types, origins, and responses to failure for specific students in specific situations.

Table 1 provides an overview of each dimension of the failure response process for the seven dyads. Looking across one row tells the story of a single dyad's exchange over a brief period, and looking between rows reveals the diversity in approaches taken by the dyads. In order to capture how these three processes relate to one another, I draw an analogy to Cultural-Historical Activity Theory (Cole & Engestrom, 1993), which views each aspect of an activity

| Pairs | Finding the obstacle | | | | | Causal search | | | | Intervention | | |
	Found when?	Found by whom?	What is the obstacle?	Prior or future obstacle?	Initial guidance offered?	What causes?	What causes of causes?	Where is the cause?	Causal search when?	Past or future actions?	Control over intervention?	Actions needed?
SF/TM	Seconds after	Tutor	Laughing	Past action	Immediately corrected	Friend and his mango	N/A	Outside student	After obstacle & after answer	Future actions	Tutor gives idea and student responds	New idea plus coercion
SF2/TO	Seconds after	Student	A fraction subtraction problem	Future action	No initial guidance	Confusion	Negative sign	Inside student/ Outside student	Before obstacle	Future actions	Tutor gives idea and student responds	New idea
SD/TC	Seconds after	Both	Drawing a model of multiplying fractions	Past action	Immediately corrected	Confusion; Inability; Learning	Tutor's actions	Inside student/ Outside student	After obstacle &before answer	Postpone decision	Postpone decision	Postpone decision
SJ/TF	Seconds after	Tutor	Recent calculation in fraction division problem	Past action	No initial guidance	(Hard problem)	N/A	(Outside student)	(After obstacle &before answer)	Past actions	Tutor locates & student resolves obstacle	Locate the obstacle & second chance
SZ/TC	Seconds after	Tutor	Adding two numbers	Past action	No initial guidance	Confusion; Working quickly	N/A	Inside student	After obstacle & after answer	Future actions	Tutor gives idea and student responds	New idea
SU/TK	19 seconds after	Student	A division problem	Future action	No initial guidance	Confusion	N/A	Inside student	Before obstacle	Future actions	Tutor gives idea and student responds	New idea
SG/TN	3 min 3 seconds after	Tutor	Somewhere on homework page	Past action	No initial guidance	N/A	N/A	N/A	N/A	Past actions	Tutor locates & student resolves obstacle	Locate the obstacle & second chance

Table 1: This table details how each dyad handles the failure response process. Parentheses mark uncertainty about the inference I have made.

system (subjects, objects, tools, divisions of labor, communities, and rules) as capable of influencing each other aspect. A shift in one aspect of the system trickles through to influence other aspects. There is also a mutually influential relationship between the three failure-response processes. Below, for each process discussed in this chapter, I make a few observations about how decisions made within that process constrain or give meaning to the other processes.

5.7.1 *How finding the obstacle connects to the failure response process*

The moment when participants define an action as an obstacle strongly shapes what remains of the failure response process. With the flow of activity halted and an obstacle identified, participants search for causes and interventions relative to that obstacle. If participants identity a math problem as an obstacle—and not, for example, the action in which the student asked a question without first attempting to solve the problem, or the action in which the teacher assigned a monotonous, conceptually unmoored math assignment—then however effectively participants document the causes of the obstacle and implement an intervention, then the obstacle may reappear again and again. Constructing something as an obstacle starts the selection process that determines who will invest time and energy to change the course of the activity.

5.7.2 *How timing obstacle construction connects to the failure response process*

How much time elapses between the obstacle and the recognition of the obstacle places different constraints on the causal reasoning process. Catching the obstacle as it arises leaves open the opportunity to notice what occurred just prior to the obstacle, whereas catching the obstacle half a minute or several minutes later may mean that events leading up the obstacle have been lost in memory. As more time elapses between the obstacle and the recognition of the obstacle, cognitive tools such as memory, reasoning, and physical artifacts (films, photographs, markings

on a page) would need to be increasingly relied on to recreate the past in search of the causes of the obstacle.

5.7.3   *How prior work connects to the failure response process*

What are the substantive differences between describing an obstacle that emerged out of a past public attempt and describing an obstacle that the participant has not yet publicly attempted? When participants have publicly worked through an activity that gave rise to an obstacle, the search for the cause of the activity can draw in part on the actual actions that preceded the obstacle. The student's own actions become data to fuel the causal search process, and the intervention could then better target an actual cause of the obstacle. In contrast, if the participant pauses ahead of the obstacle, without publicly attempting to approach it, then the attribution process necessarily involves imagining or simulating what may be causing the student's reluctance to move forward.

For example, TO suggests that SF2 solicited help on a problem because of a negative sign that lead to his confusion. She had not seen SF2 struggle with the negative sign—her proposal was a small causal theory about what had held SF2 back. In contrast, because SJ works through the problem in front of her tutor, TF sees that the action of taking the reciprocal presented her with an obstacle, and the failure response process can use the student's past work to guide the resolution to the obstacle. Having more information about how the student works through the activity does not guarantee finding the correct etiology of the obstacle—nor would it always be possible or cost-effective to have students make a first attempt—but it would give teachers a valuable angle into what students can accomplish independently before intervening.

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5.7.4 How obstacle and resolution descriptions connect to the failure response process

How does the precision with which participants label an obstacle and its resolution relate to the causal search and intervention processes? Knowing that an obstacle exists, but not what the obstacle is, means that students have to devote effort first to locating the point of failure. This moves the process of seeing the obstacle onto the interpersonal plane. In contrast, providing an immediate description of the obstacle directs the failure response to search for causes and resolutions. Even further, swiftly giving the normative solution to the problem means that the failure response process can focus on other things, such as planning for future obstacles. For example, when TM immediately tells SF that he needs to quiet down, both the obstacle and the expected normative action have been labeled. SF then immediately turns to blaming a peer for causing his distraction. Similarly, after TC corrects SZ's small miscalculation, both he and SZ immediately explicate causes of the obstacle: working too quickly and confusion. TC and SZ then spend time on how SZ could avoid the obstacle in the future. With the obstacle recognition and normative action already understood, it may be that participants can promptly draw attention to possible causes and interventions. These two options mark different pedagogical opportunities. Whether we have students participate in the act of constructing the obstacle or direct immediate attention to understanding the etiology and resolution of the obstacle can promote different learning goals.

5.7.5 How causal search connects to the failure response process

The causal search process involves participants positing that some event(s) created the obstacle. Because the tutors and students make public the search for causes, the process must do some work for them, whether assigning responsibility, explaining one's circumstances, or feeding into plans to intervene. That participants disagree about these causes shows the inherent haziness of

documenting causal relationships, and sets the stage for issues of power to determine which causes stick and how they propel upcoming interventions. Furthermore, by locating causes within themselves, other people, and the environment, participants fashion causal chains that constitute more complex stories about failure than what traditionally unfolds in post hoc survey and interview research.

5.7.6 *How the locus of causes connects to the failure response process*

Because causes spring out of specific locations in an activity—what attribution theorists have labeled internal and external loci of an attribution—the negotiation over what causes failure plays a large role in the intervention process, specifically in how participants decide what resources to deploy and who is responsible for deploying them. As such, the causal search process, when understood in the context of the forthcoming intervention, becomes as much a political act as anything else, in the strict sense of framing who will have to allocate time and effort to the resolution.

Not surprisingly, then, tutors and students disagree about the cause(s) of the obstacle. In SZ and TC, did failure derive from working too quickly or getting confused? If speed caused the miscalculation, then SZ should slow down (which may have the opportunity cost of missing parts of break time). If confusion caused the miscalculation, then SZ and TC need to work together to think of a new way to organize her math activity to avoid her confusion (which might involve the presentation of new math strategies). Similarly, did the friend with the mango or SF's own inability to focus cause SF's distracting laughter? If the former, then TM and SF would need to find a way to get the student with the mango to stop his activity. If the latter, then SF would be expected to ignore the mango and/or regroup quickly to continue his work. Locating

the cause of the obstacle in a particular location in the activity frames whether the student or tutor (or institution, family, community, etc.) will be expected to resolve the obstacle.

5.7.7 How the timing of causal search connects to the failure response process

When the causal search process occurs relative to finding the obstacle and intervening with a solution presents an additional constraint. We saw participants formulate attributions of failure after they had found an obstacle but before they had ever publicly attempted the obstacle. Positing a cause of an obstacle that the student has not publicly attempted necessarily involves imagining or simulating what may be holding the student back. In contrast, positing causes after the student has worked publicly, albeit unsuccessfully, through an activity can provide information to the tutor and the student that will help them interrogate what events may have caused the obstacle. Finally, searching for causal ascriptions both after participants have attempted the obstacle and after participants have intervened provides even more evidence for what caused the failure, as the participants have access both to the original actions that lead to the obstacle and to how the student responds to new actions that moved the student past the obstacle. Each of these situations falls on a spectrum of how much information participants have in their causal search, which crucially sets the stage for the intervention.

5.7.8 How division of labor in the intervention connects to the failure response process

Because multi-party human activities involve divisions of labor, in which participants parse an activity into its component resources and actions, and allocate the responsibility of accomplishing those actions to participants to different extents, the intervention process enacts some practices the student manages and some practices the tutor manages. Attribution theorists have referred to this dimension as controllability, in the sense of how much individuals believe

they can control the causes of their successes and failures. Within the flow of a tutoring session, interventions denote what students can control in resolving the obstacle. To hearken back to an example, when TM blames a peer for distracting him, SF threatens to impose a penalty (extra time on reading) if TM cannot ignore the distraction and get back to work. TM's intervention suggests that TM knows how to control his attention—he simply needs to be coerced to deploy those skills. In the same way, some of the other interventions I described (e.g. SF2/TO) suggested that tutors control idea generation (e.g. subtract one number from another) and students enact responses to those ideas (e.g. providing an answer to the subtraction arithmetic problem). The implication of divided-labor interventions is that the tutor and the student share the responsibility of guiding the resolution to whatever caused the obstacle. From a narrative standpoint, interventions reveal participants' tacit assumptions about what students can control in resolving the cause(s) of an obstacle.

5.7.9   *How the content of the intervention connects to the failure response process*

In addition to sending a message about what students control and what tutors control, the intervention suggests what students need in order to respond to the obstacle. If in response to a state of confusion that causes inaction on a math problem, the tutor offers a new math idea about the problem, then the intervention creates a situation in which new ideas are needed to stamp out confusion. Confusion, however, is a state of mind that could spring from different causes. Targeting the intervention around math knowledge makes a strong statement about how new math ideas—not renewed focus, memories of known ideas, or lessening fears of failure—help to move past confusion. Similarly, TM's focus on imposing a penalty on SF for his distraction suggests that he does not need new skills to overcome the obstacle. The intervention suggests that SF fully knows how to gather himself and focus; what he needs, to put it broadly, is for

someone to make him deploy those skills. From a narrative standpoint, interventions reveal participants' tacit assumptions about what actions are needed to resolve the causes of the obstacle.

5.7.10 Summarizing interconnected dimensions of the failure response process

In summary, the connections between these three processes create a failure narrative jointly constructed in the moment. The participants, in working through an obstacle to sustain progress on math homework, also end up constructing a theory of what went wrong, why it went wrong, and what can be done about it. How much time elapses after the obstacle, what participants choose to call an obstacle, and whether they publicly attempt to overcome the obstacle all have implications for how participants can account for what caused the obstacle, who is expected to mobilize resources to resolve the obstacle, what participants can control in that intervention, and what it says about the actions needed to move past a trouble spot. The configuration that unfolds creates a situated response to failure, a practice or routine that says a great deal about what the members of the after-school center think about failure, where it comes from, and what to do about it. An important caveat to these conclusions is that the limited sample size in this preliminary analysis means that I do not have multiple repetitions of failure for the same dyad. One would need a larger sample size, tracked over several sessions, to connect interactional moments of failure to post-hoc stories about failure, and to understand how stories layer up and become recycled over time. These are important considerations for future research.

5.8   Connections to psychological models of attribution theory

Attribution theory began as a framework to describe how individuals think about their own successes and failures after the fact and mediated by surveys and interviews (e.g. Weiner, 1983;

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Graham, 1991). More social version of this default psychological model exist, in which participants watch videos of teachers and students working together, or interact with teachers and state what they believe those teachers attributed to the learning struggles (e.g. Graham, 1985). This latter research moves toward an interactional account, but for important experimental reasons, constitutes social communication as the one-way transmission of ideas.

In traditional attribution theory, causal ascriptions such as distraction, a friend with a mango, and confusion are understood to involve three causal dimensions: locus, controllability, and stability. Where are the causal ascriptions located, can they be controlled, and are they stable? I set out to re-evaluate attribution theory from the perspective of participants' public responses to failure during routine activity, in the spirit of recent conversation analysis studies of attributions in sports psychology (e.g. Finlay & Faulkner, 2003) and parent-teacher conferences (e.g. de Haan & Wissink, 2012). The turns in talk and the physical actions I describe in this chapter as constructing, attributing, and intervening relate to one another temporally and conceptually in the local context.

The locus, controllability, and stability dimensions take on new meaning in an interactional account. The *locus* of causal ascriptions, or their location in activity, was marked either grammatically in language (e.g. "I" or "You") or through environmentally coupled gestures (e.g. using the finger to point to a math sign on the paper). The difference between the classic attribution theory account and this interactional account is that participants in live conversation outline chains of causal sequences that stretch across different locations in the setting. I examined the statement about a *tutor making the student confused*, a public causal account that stretches the locus of two causes across the body of the tutor and the body of the student. Taking into account the distributed nature of all human activity (Hutchins, 2014), we

may need to rethink the veracity and comprehensiveness of causal ascriptions of failure. Participants in their pubic practices of knowledge construction could learn to construe causal ascriptions, such as ability, which have historically been understood to be internal processes, as stretching across different locations in the local context.

The controllability of causal ascriptions also takes on new meaning in an interactional account. The classic version of attribution theory considers controllability to refer to the participants' capacity to influence, shape, or manage the causes of failure. In an interactional account, participants can organize interventions around proposed causes. Interventions divide the labor in such a way that students control some aspects of the activity and tutors control some aspects of the activity. However, other aspects of control in goal-oriented knowledge-construction activities are less focused on how to control the cause(s) of the failure. Two cases—the student forgetting the reciprocal math action and the student laughing distractedly—involve interventions that guide the student toward the normative math/behavioral action, but do not address the cause of the original obstacle. The interactions remain agnostic about whether the student can control the cause. The interventions instead involve the students correcting the obstacle (taking the reciprocal and re-focusing) without addressing whether the student can control the occurrence of the obstacle if the same cause arises. To be even more concrete, the students in these encounters move beyond the trouble spot without ever reflecting on how they can control their actions to avoid the obstacle if it reappears. Controllability, in this way, can signify controlling the route toward the normative action without involving how to control the cause of the obstacle.

In public dialogue, participants also address the stability of causal ascriptions. The standard account of stability refers to whether the cause will be expected to recur. In one

exchange that follows this pattern, a tutor suggests that a student working too quickly is causing mistakes, and the tutor intervenes to request that the student slow down. In soliciting an intervention designed to curb upcoming obstacles, the tutor denotes that the cause of working too quickly will recur unless he asks for a different approach to the activity. In two other cases, tutors notice students making very rare mistakes—missing two problems out of 40 and only once forgetting to take the reciprocal action. Simply put, the causes of these obstacles are unstable in the environment because the students encounter obstacles to their goal of completing accurate homework very infrequently. Both of these interventions ignore what might have caused the mistake and focus instead on intervening to resolve the obstacle. A full understanding of how interactions connote the stability of the cause is beyond this dissertation, but these observations raise the possibility that the attribution and intervention processes involve implicit assumptions about the stability of the causes of obstacles.

5.9 Stories about failure and epistemic cognition

Chapter 6 transitions to a discussion about epistemic cognition, specifically the sources of knowledge that students and tutors recruit to construct math claims. The single case study in the next chapter presents an analysis of the moment-to-moment integration of perception, reasoning, introspection, memory, and testimony, resources that philosophers have viewed as critical to knowledge construction (Chinn, Buckland, & Samarapungavan, 2011). The purpose of drawing in epistemic cognition in a discussion about failure is to begin to see the complex origins of knowledge construction, which if recognized by participants, could fuel more comprehensive— and possibly actionable—stories about what causes *inability* (however brief) to construct knowledge and how to intervene. The educational implications of these theoretical points are that students and tutors can reflect on the multidimensional pathway that generates knowledge and

debug these layered routes through semiotically rich ecologies to more comprehensively track and resolve failure.

Chapter 6
Sources of knowledge in mathematics tutoring

This chapter addresses my second set of research questions: What epistemic resources merge together for elementary-school students to produce solutions to math problems? And how comprehensively do stories about failure account for the range of epistemic resources deployed in interaction? The focus is on the notion of ability, which in failure studies that draw on attribution theory, has often been conceptualized as an internal, stable, and uncontrollable trait. Failure, in turn, when caused by lack of ability, is understood to have been inevitable and cannot be rewritten in the future. This chapter presents a situated account of knowledge construction that questions this conceptualization of ability. In recognizing ability as the product of actions that encompass interactional pathways that connect multiple epistemic resources, I argue that the types of failure stories seen in Chapters 4 and 5 could evolve to more comprehensively account for the quality and sequential arrangement of epistemic resources. New stories about the causes of failure could in turn open up actionable and effective interventions.

6.1   Introduction

From where does *what we know* come? In activity, what sources of knowledge (SoK) do people recruit to generate claims about their worlds? While philosophers have long agonized over this question, educational researches have only in recent decades conducted empirical inquiries into how students weigh, recruit, and think explicitly about SoK (Hofer & Pintrich, 2002). Focused on teaching and learning, educational researchers inquire less into what counts as rational/justified selections of sources according to philosophical criteria than into how students

formulate beliefs about and select from knowledge sources during moment-to-moment learning activities.

I define epistemic cognition as the (often tacit) process by which communities come to know relevant aspects of their worlds during inquiry and activity. How people perceive their environments, organize their environments, recruit physical tools, tap past memories, reason through situations, monitor their own understanding, and share ideas interpersonally, and how these resources occur in sequence and simultaneously in activity, create situation-specific pathways to making claims about the world. Epistemic cognition, in this broad sense, constitutes how participants work alone or together in a specific environment to assemble resources, whether one after the other or several at once, toward knowledge and understanding.

In educational psychology, the term *personal* epistemology, in contrast, refers to students' explicit beliefs about knowledge (Kitchener, 2002), and thus encompasses a different range of phenomena surrounding the topic of knowledge (see Sandoval (2005) for further discussion). Instead of studying what students believe about knowledge construction, I am concerned with how participants make tacit commitments (Chinn, Buckland, & Samarapungavan, 2011) to know their worlds in a certain way (see also Louca, Hammer, Elby, & Kagey, 2004). For example, Rosenberg, Hammer, & Phelan (2006) document how over the course of a 15-minute conversation about the rock cycle, students move from an epistemic commitment of relying on the worksheet to one of starting from what they knew and using reasoning. I aim to conduct a similar inquiry into students' enacted epistemic practices, albeit taking into account more than the verbal channel and looking for the simultaneous and sequential assemblage of sources of knowledge over a much shorter time period.

Frameworks that recognize the sources of knowledge students recruit in activity tend to honor a wide array of resources (Goodwin, 2007). For example, recent epistemic cognition theorists have suggested that knowledge derives from many sources—perception, introspection, memory, reasoning, and testimony—and, most importantly, that these sources interact with one another (Chinn, Buckland, & Samarapungavan, 2011). Instead of viewing sources of knowledge in the binary terms of internal versus external experience, this framework suggests that sources of knowledge are varied and not mutually exclusive. Moreover, it is the interaction between these SoK that impact cognitive acts related to knowledge. This re-framing is important because it has the capacity to recognize a greater spectrum of epistemic actions and re-orient the types of questions researchers ask students about epistemology in survey and interview research.

In this chapter, I attempt to ground hypothetical anecdotes about interacting SoK in an empirical study, developing a situated account of how interactions between inhabitants of a learning community successively laminate sources of knowledge into activities that create opportunities for sense-making and for showing, recognizing, and trusting epistemic contributions.

6.2   Mathematics knowledge in situated cognition

How have situated cognition researchers described mathematics knowledge? Since the situated turn in cognitive science, researchers have accommodated the possibility that some relevant dimensions of thinking happen beyond internal neurons of the brain—in what is often called *extended cognition* (Clark & Chalmer, 1998). In mathematics, this means that written and visual interactions with numbers on paper—or mathematical models run on computers—can become vital, external (to the brain) elements of the cognitive system that constitutes thought. To

highlight this point, I quote Hutchins (1992) at length, in a passage about Alan Turing and the origins of cognitive science:

> "The heart of Turing's great discovery was that the embodied actions of the mathematician and the world in which the mathematician acted could be idealized and abstracted in such a way that the mathematician could be eliminated. What remained was the essence of the application of rules to strings of symbols. For the purposes of producing the computation, the way the mathematician actually interacted with the material world is no more than an implementation detail" (p. 363).

The above passage documents how cognitive science flattened the sociocultural system in which mathematics takes place into an abstract, symbolic world. As Hutchins argues, the resulting invention of a computer is a masterful tool to extend the human capacity to think through mathematics, but this in no way justifies that the human cognitive system that engages with mathematics should be recast in a computational metaphor. Instead, we can recognize that all of human cognition is distributed at different scales—whether across neurons; across an individual, his body, and his local tools; or across people in society—such that the center of a distributed system would shift depending on the knowledge demands of the activity and the social setting at hand (Hutchins, 2014).

In mathematics, this means that the placement of the body and eyes relative to written inscriptions on paper becomes an action integral to the production of knowledge claims, and gathers meaning against the ground of internal math calculations executed in working memory. Because of the low cognitive cost associated with opening the eyes and seeing a visual experience of the world, for example, the brain does not bother to duplicate and store in working memory everything that it sees externally—instead, we open our eyes and glance at aspects of

the world on an "as-needed basis" (Robbins & Aydede, 2009). The paper preserves the past actions of the hand, saving the lead markings from a pencil, until the moment the participant's cognitive system needs to retrieve the details. Moving the eye to gather information becomes less costly than storing all of the written prompts, digits, and operations exclusively in working and short-term memory.

The upshot of documenting the sociocultural system through which people interact with mathematics is that researchers, teachers, and students can better recognize how the body and perception interact with the visual world of written math symbols. When introducing new material in mathematics, for example, teachers rely on gesture to demarcate how different parts of the math problem relate to one another (Alibali et al., 2014), and teachers' gestures in this regard have even correlated with student learning gains (Singer & Goldin-Meadow, 2005). Students' kinesthetic interactions with visual interfaces that cultivate embodied knowledge of proportions can also function as scaffolding for reasoning about symbolic proportions (Abrahamson, Lee, Negrete, & Gutierrez, 2014). In a now classic paper on the situated basis of math tutoring, Stevens and Hall (1998) describe how the actions of a tutor to cover up parts of a graph with her hands creates a new way to visualize the graph and provides one of the elements in the ecology of the learning session that gives way to conceptual change.

The goal of this chapter is to formulate a situated account of the construction of mathematical knowledge in the well-defined context of after-school mathematics tutoring. Building on foundational notions of knowledge in situated cognition, I extend Chinn, Buckland, and Samarapungavan's (2011) description of sources of knowledge into a fine-grained interaction analysis of how one student comes to know the answer to a math problem. I focus on participants' public acts of communication as evidence of the sources of knowledge they recruit

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to formulate solutions to math problems. Before looking at the data, I make a few remarks in the coming section on the value of this research for epistemic cognition and attribution theory.

6.3 Epistemic cognition in social interaction

The analysis that follows will contribute to the field of epistemic cognition in a number of ways. First, educational researchers have lately called for the study of situated beliefs about knowledge that are more closely tied to practice, whether as practical epistemologies (Sandoval, 2005) or proximal epistemologies (Hogan, 2000). Interaction analyses that carefully attend to the sources of knowledge on which participants draw in learning environments could help guide the questions PE researchers pose to students and teachers in survey/interview research. Instead of drawing a dichotomy between internal and external resources, these post hoc reflection measures could ask students to discuss finer-grained epistemic resources, including the temporal arrangement of those resources.

Secondly, research on the enacted character of epistemic cognition (e.g. Rosenberg, Hammer, & Phelan, 2006), while effective in honoring a greater range of resources students bring to the table during knowledge-related activities, treats interaction almost exclusively as a verbal phenomenon. Verbal transcriptions tend to highlight the semantic/symbolic content of thought while remaining myopic about the physical materials, body movements, and social interactions that give meaning to speech and vice-versa. In this study, I use the full array of tools in multimodal interaction analysis to throw light on the deployment and lamination of distributed sources of knowledge over time periods in the range of a few seconds.

Thirdly, this study will ground hypothetical anecdotes about interacting sources of knowledge from Chinn et al. (2011) in analyses of a student and tutor engaging in routine epistemic practices at an after-school learning center. In so doing, the study throws further light

on the gulf that can exist between professed beliefs about knowledge and routine interactions with knowledge (Hammer & Elby, 2002). The speed with which our cognitive and social systems layer up resources for knowledge construction is staggering and thus presents considerable challenges for how educators can design learning experience that help students reflect productively on those resources.

Finally, the pace in which participants recruit a diverse array of resources for knowledge construction raises important questions about teacher training and student dialogue about epistemic cognition. Whether we can expect participants to become aware of the situated character of their thinking and what this awareness would accomplish are difficult but central questions for future research on epistemic cognition. I will return to these questions in the discussion section.

6.4 Method

Participants. The analysis in this chapter focuses on how one dyad, Juana (SJ from Chapter 5) and Felipe (TF from Chapter 5), handles a mistake Juana makes when solving a division of fractions problem. I selected this exchange specifically for its relevance to the research question guiding this chapter. At present, the purpose of the project is to describe epistemic cognition through a fine-grained analysis of public practice, not to argue for the generality or external validity of these claims. Other information about the participants and the design of the study can be found in the methods chapter of this dissertation.

Analysis. The central tenet of interaction analysis is to describe the patterns through which participants interact with one another during moments of communication (Jordan & Henderson, 1995). The goal is to avoid making claims about participants' intentions, desires, or beliefs, and instead to describe the work accomplished between participants and available to be

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viewed in public. As such, I aim in this chapter to describe how the tutors and students organize their own epistemic practices. I look for moments when participants raise the possibility of using a source of knowledge or when participants act in such a way that they draw directly on a source of knowledge (and make that practice visible).

For this analysis, I created multimodal transcripts that integrate participants' talk with their physical activities and their surroundings. The transcripts become acts of analysis, as they parse and highlight subsets of the innumerable aspects of social interaction (Ochs, 1979). In the following paragraphs, I describe how I define each source of knowledge construct, drawing on Chinn, Buckland, and Samarapungavan (2011), and what I would consider evidence of those sources of knowledge in interaction.

Perception: Perception refers to cognitive experiences that arrive through the senses. Much of the information that arrives through the senses would be irrelevant to mathematics knowledge construction, such as the sound of a car driving past the school or the aftertaste of the day's lunch. When students and tutors use sensory information to inform some part of the process that gives rise to epistemic ends (knowledge, understanding, models explanations, etc.), then perception becomes a source of knowledge. An example involving visual perception would be an animal on an open plain lifting its head, rotating its neck, and scanning the horizon in search of predators and prey—what Sterelny (2003) calls an epistemic action. In epistemic terms, the animal knows that prey is on the horizon because its eye in coordination with its cognitive visual system locates and displays the appearance of the prey. That visual representation gathers meaning relative to the animal's goals and other cognitive systems that interpret the experience.

In mathematics tutoring sessions, I consider acts of visual perception to be a source of knowledge when the student involves perception in the sequence of actions that generates a math

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claim. If participants are looking at each other and talking about a memory from the past (without gesture), the visual experience does not contribute to knowing about the past memory; the two could have held the same conversation over the phone. However, if participants are discussing how "this should be changed" or responding to a question about "what went wrong here?" and they refer to written numbers and symbols on paper, then visual perception is essential to the meaning of the utterance and the meaning of the action in response to the utterance. In summary, participants in the interaction need to both display an act of perception and that act of perception needs to be relevant to the knowledge construction process.

Memory: Just as information central to the knowledge construction process can come from the senses, it can also come from re-creations of past experiences through memory. The mnemic function of the brain vastly expands how the human cognitive system can know, understand, model, and explain the world. Whenever people use memories of the past as information sources to orient what they understand or know, then memory becomes an epistemic source.

Using the tools of interaction analysis, it is difficult to make claims about what memories participants sifted through and which they ignored. Instead, we can look at how participants make visible in their actions events that could only have come from acts of recollection. If we can rule out that the senses, immediate testimony, and reasoning could not have given rise to an idea proposed by a participant, then we can conclude that memories of the past contributed to the knowledge claim. Participants may even make relevant in their dialogue the source of their thinking, describing in words how they "remember" or "recall" an experience.

Testimony: Social interactions and communities with formal divisions of labor create situations in which participants use each other's statements/ideas as resources for knowing their

worlds. On a navy ship, computations performed by members of the navigation team in one part of the ship are passed along to members in other parts of the ship, and these contributions unite to allow the captain to *know* how to navigate the ship safely (Hutchins, 1995). More broadly, we routinely trust statements from other people. In routine social discourse, we may know that a movie starts at 7 p.m. because a friend said so. We may know that Congress voted to declare war because the newspaper printed a story about the event. Any act of communication in spoken or signed language, body language, gesture, or physical action that another participant experiences and then uses to shape what they know about their world counts as an epistemic source.

In the context of mathematics tutoring sessions, students incorporate tutors' ideas about mathematics into their answers to math problems. Any time that a tutor or peer communicates something about mathematics that shapes the students' problem-solving process, then testimony has been used as an epistemic source.

Reasoning: The reasoning process can be described narrowly as logically sound reasoning (e.g. formal deductive reasoning), but at the early stage of this program of research, I adopt a much more liberal definition of the construct. I consider the imagination, the application of rules, computations in working memory, physical epistemic actions, conceptual blending, and any other form of cognition in which different processes are brought together to create a new idea to be acts of reasoning. It may well be worth separating these acts of thinking into different subtopics in later research, but for now, I will adopt this general description of reasoning.

Some physical acts of reasoning, such as moving Tetris blocks (Kirsh & Maglio, 1994), handling blocks of cheese in the supermarket (Lave, 1988), using physical geology models (Kastens, Liben, & Agrawal, 2008), or gesturing a science model (Clement & Steinberg, 2002), can be viewed in public and described as such. Other acts of reasoning happen in cognitive

spaces that an observer cannot see, such as a person imagining how the planets rotate around the sun (Subramaniam & Padalkar, 2009). In the non-experimental setting of most interaction analysis research, it would be speculative to describe in detail what happens in these internal spaces. However, based on participants' language and physical actions, we can see how they make relevant internal reasoning—beyond perception and simple episodic memories—in their actions. For example, if students apply a generic math rule to a specific math problem, they have publicly instantiated reasoning about the application of categories to instances. In situations when participants make relevant in the public space an act of reasoning that happened in a private space, or when they publicly state how they reasoned through a process, we can articulate that reasoning contributed to the epistemic claim.

Introspection: The process of monitoring one's own actions and thinking, which can be classified under the larger umbrella of metacognition (Flavell, 1979), is central to the knowledge construction process. Piaget describes the process of reflection in his genetic epistemology (Piaget, 1983) as central to striking a balance between accommodation and assimilation. Here, tracking one's own progress en route to understanding, knowledge, and explanation is essential to arriving at a point where the knowledge construction process ceases and claims are made. Whereas the first four epistemic resources help participants achieve the epistemic end of knowledge, the epistemic resource of introspection helps participants track their own learning, a process for achieving the after-school center's epistemic end of understanding.

In practice, there may be many moments of internal reflection on one's own cognitive processes. Those that I recognize in this chapter are the ones that participants make public in their interaction as part of the process by which they evaluate their own understanding. When the public space contains depictions about how an individual is thinking about his/her own thinking,

then the participants can seek out new sources of knowledge, experience them in new ways, or in other ways address the shortcomings of the process of justifying the claim. The process of reflecting on thought and action becomes a crucial resource for knowing that one has arrived at the epistemic end of understanding. This is in some sense the most personal aspect of the epistemic cognition process, the moments where epistemic claims are placed in coordination with the sense-making practices of the individual.

Constructs summary: In listing each of these sources of knowledge separately, I do not mean to imply that they deploy in isolation during math tutoring sessions. These are not mutually exclusive experiences. Instead, these definitions are intended to state how I justify the presence of a source of knowledge in social interaction, and I am fully open to the possibility that they will overlap and appear in rapid succession, shaping each other and the knowledge construction process. We know, for example, that many of the epistemic actions that take advantage of hands manipulating objects in space would be fruitless without the perceptual system registering the visual scene. Describing how these sources of knowledge unfold in interaction with one another, in fact, is one of the core contributions of this chapter. I also do not mean to suggest that other sources of knowledge beyond these five could not be involved in knowledge construction. Instead, I am starting this program of research with a proof of concept that departs from the model proposed by Chinn, Buckland, & Samarapungavan (2011).

6.5   Results

In Chapter 5, we saw Juana (SJ) and Felipe (TF) respond to Juana forgetting to take the reciprocal on a division of fractions problem. Toward the middle of their exchange, Juana and Felipe explain, "it got hard," and I noted that this phrase could have referred either to an attribution of failure (the external math problem got hard) or to the intensity of the obstacle in

their path (they simply are experiencing an obstacle). I point this out now to highlight the short amount of time that Juana and Felipe devote to understanding the cause(s) of the obstacle and also the vagueness of their account. In this chapter, I present a distributed take on how Juana constructs knowledge with Felipe as a way to consider how she and Felipe, and by implication other tutor-student dyads, could co-construct more comprehensive, and potentially productive, stories about failures and successes during homework.

In the episode, Juana (a 4th grade student) has been working on a division of fractions math problem (8 1/3 ÷ 3 2/3) when Felipe, her tutor, catches her making a mistake. To provide an overview of what happens in this interaction, Juana pushes back, arguing that her answer is correct, and then after a lengthy reflection on all of her accurate work on the problem, Juana notices the point where she forgot to take the reciprocal. She corrects her error and moves on.

There are two background epistemic ends at the after school program that bare fleshing out. The first is that students need to have the correct answers written on their math homework, barring unusual circumstances, in order to move on to STEM enrichment projects. As an epistemic aim (Chinn, Buckland, & Samarapungavan, 2011; or epistemic end in Chinn, Rinehart, & Buckland, 2014), this means that students need to create accurate math knowledge on their assignments. The second homework norm is that students need to independently understand what they are doing, in the sense of understanding what to do in the moment and what to do on future math problems. This epistemic aim can be described as understanding or comprehension. The concept of understanding is not the same as deep conceptual understanding (see the discussion on procedural understanding versus conceptual understanding in Hallett, Nunes, Bryant, & Thorpe, 2012). I use the term here to mean that students need to understand enough of what do with the resources available to them at the after-school program to reach the epistemic aim of

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accurate knowledge. Both epistemic aims—knowledge and understanding—are in play during math homework, and participants deploy different epistemic resources to reach those ends.

Let us now look at the details of the interaction and start to unfold how a tutor and student, SJ and TF, work together to recruit and laminate epistemic resources in their knowledge-construction activity. We start with the point where Felipe intercepts Juana's work by asking her to "Hold on" during a division of fractions problem (8 1/4 ÷ 3 2/3). Felipe's intervention into Juana's work occurs because Juana has forgotten to take the reciprocal of the fraction after turning the division sign into a multiplication sign. She should have flipped the fraction 11/3 into 3/11 after she changed the division sign to a multiplication sign, but instead, she starts to draw an oval around the numerator of one fraction and the denominator of the other fraction, an action that in the past dozen or so problems on the assignment signaled that Juana was about to take the reciprocal. Felipe intervenes in the following way:
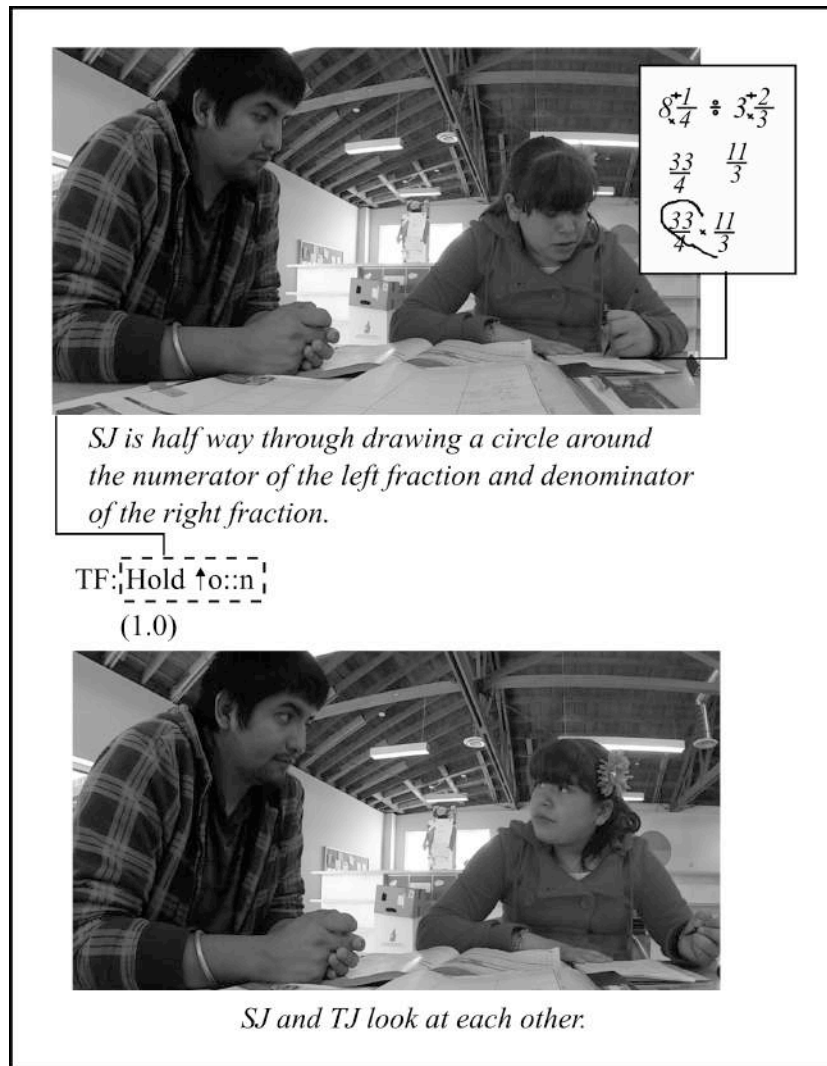
Figure 43: Felipe is watching Juana solve a division of fractions problem and asks her to "hold on."

In this turn, Felipe provides incipient testimony to the accuracy of Juana's work. The comment carries weight in the interaction; Juana immediately lifts up her pencil, stops working, and looks at Felipe. The entire contextual configuration of bodies, papers, and textbooks at the tutoring center is built to create the allowance for immediate testimony. The tutors' placement next to the students, and the tutors' frequent looks over the shoulders of the students as they work, allow for tutors to comment immediately on the veracity of student progress. The event that sets in motion doubt about Juana's work, the event that leads to a new fork in the homework process toward the epistemic end of accurate math knowledge and math understanding, is this

moment of the tutor's testimony. The testimony is epistemically significant; Juana knows to doubt the accuracy of the math knowledge she has produced because the tutor has intervened.

We can view this moment of testimony as simultaneously laminated over Juana's visual perception and reasoning. The phrase, "Hold on," overlaps Juana's visual inspection of her homework and her public form of reasoning through each step of the problem. But neither perception nor reasoning shifts the interaction toward a discussion about failure—the tutor's testimony is what redirects the interaction. The testimony resonates throughout the other epistemic resources, triggering Juana to pause her work—suspending her gaze and her physical actions—to launch a conversation about the veracity of her recent work.

The very next moment of the dialogue explicitly redeploys the epistemic resource of visual perception. Felipe asks Juana to check her work with the phrase, "*Look* at it again" (my italics):

TF: Look at it >again<.

(4.5)

$$8\tfrac{1}{4} \div 3\tfrac{2}{3}$$

$$\tfrac{33}{4} \qquad \tfrac{11}{3}$$

$$\tfrac{33}{4} \times \tfrac{11}{3}$$

SJ stares at her prior work; she looks back and forth
between the 3 and the 33; TF looks at SJ's work.

SJ: You could do: it.

SJ and TF look at each other again.
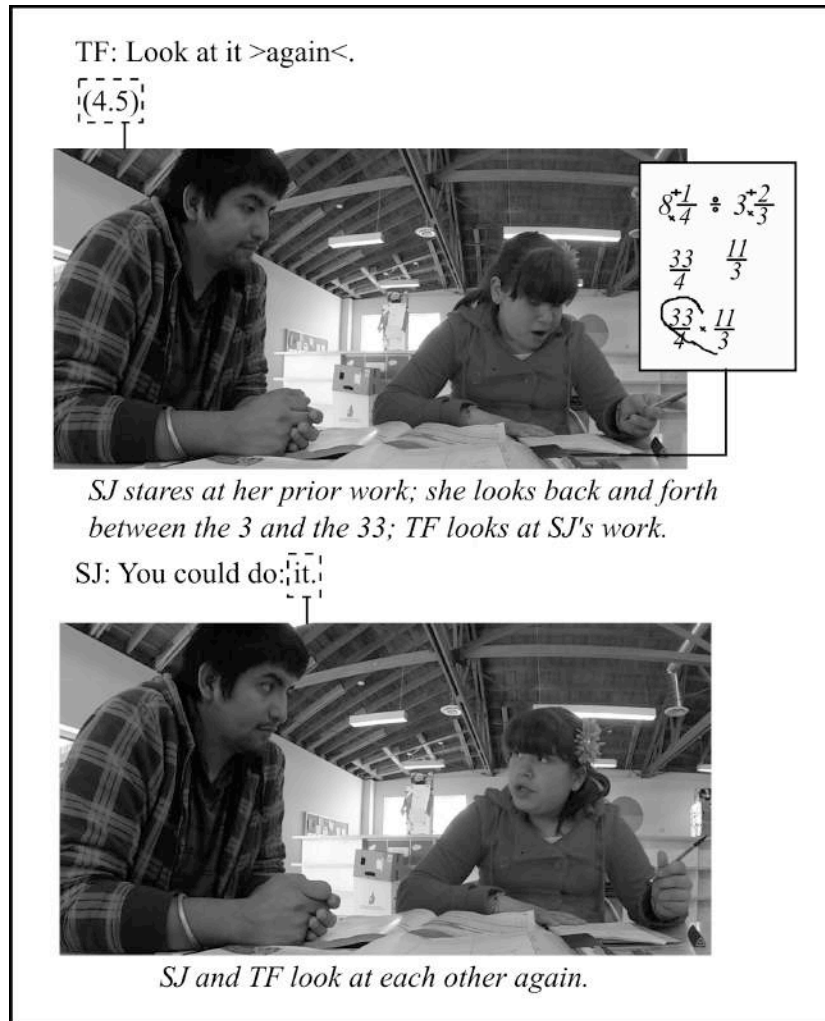
Figure 44: Felipe asks Juana to visually inspect her work, Juana looks, and then states that her approach is correct.

Felipe tells Juana to "look at it again," explicitly drawing on the epistemic resource of visual perception. As before, the verbal turn resonates with Juana, as she looks away from Felipe and back toward her work for 4 and 1/2 seconds, shifting her eyes back and forth along the diagonal between 3 and 33, the place where she last stopped working and the action she was performing. Moreover, Juana even flips her pencil from the lead side down to the eraser side down, a visible indication that she views the tutor's testimony combined with the tutor's suggestion to look back at the work as an indication that she made a mistake. Juana has been encouraged to visually inspect her own past work as a resource for knowing what to do

differently. The markings stored on paper, which captured Juana's past actions, become the data through which Juana re-experiences the past. Visual perception becomes an epistemic vehicle for considering a different solution to the problem.

Notice, however, that despite Juana's preparation to erase something on the page, she does not budge in her understanding of the problem; she states, "you could do it," which I take to mean that Juana is arguing that this is a valid math procedure. Instead of guiding Juana to notice the incorrect math action that Felipe noticed, visual perception guides Juana to notice a math action that she had already started to perform correctly, that of dividing 33 and 3 each by the number 3 to reduce both values. Juana's rebuttal to Felipe consists of describing the conclusion to the thought process she experienced while looking back at her work. The result of the perceptual action leads to a different epistemic accomplishment than the one Felipe intended—instead of seeing an improper aspect of her answer, Juana sees accurate work, which while valid standing on its own, would take her down a path toward the wrong answer. Testimony and perception are thus not enough to guarantee that Juana will notice the same non-normative math action that Felipe noticed. Moving forward in the conversation, we see that the tutor prolongs his testimony to give time for new epistemic resources to enter the picture.

In his very next turn, Felipe deploys a new epistemic resource, that of mathematical reasoning. He tells Juana to follow the steps she took on the problem.

TF: Follow your steps again.

(10.0)
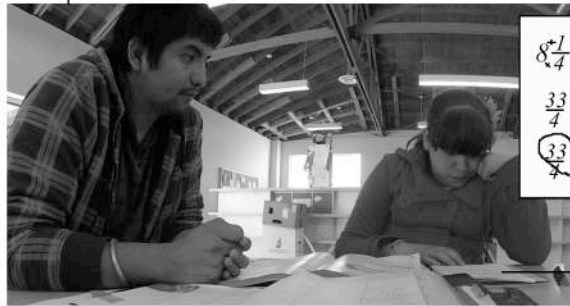
$8\frac{1}{4} \div 3\frac{2}{3}$

$\frac{33}{4}$ $\frac{11}{3}$

$\frac{33}{4}$ $\frac{11}{3}$

SJ returns to looking at her work.

SJ: It's right.

SJ gestures an open palm and looks back at TF.

(2.0)

TF squints and tightens his lips.

SJ: Cuz three goes into three once and three goes into thirty-three eleven.

$8\frac{1}{4} \div 3\frac{2}{3}$

$\frac{33}{4}$ $\frac{11}{3}$

$\frac{33}{4}$ $\frac{11}{3}$

SJ points to each digit that she names and has written.

Figure 45: Felipe asks Juana to reason through the problem, Juana looks again, and then argues why she is correct.

The resource that Felipe highlights in this step is mathematical reasoning. He asks Juana to re-examine her prior work by following the steps she took to solve the problem. In order to follow through with this request, Juana involves perception alongside reasoning. The visual markings she created on the page provide the backdrop for Juana's attempt to reason through whether she has forgotten or incorrectly performed any steps. Importantly, Felipe himself frames the suggestion in terms of reasoning, asking Juana not only to look back at the page, but also to *follow the steps* she had taken to solve the problem.

Juana persists in her prior stance, stating that the work is correct, and this time Felipe provides a silent signal of disagreement—squinting his eyes and pursing his lips. Including this gestural turn, Felipe has now provided four moments of testimony that suggest that Juana is off-track: "Hold on," "Look at it again," "Follow your steps," and the gestural squinting of the eyes (to signal suspicion or disagreement). Each move rejects a prior turn from Juana in which she had suggested that the work was correct. In this way, testimony is deeply infused within each of Felipe's suggestions to recruit a new epistemic resource. The epistemic resource Felipe introduces and directs attention to in speech may take primary focus, but the repeated calls to try something new, and the reluctance to accept Juana's rebuttals, continue to embed the interaction with testimony from the tutor. The testimony reinforces that Juana has not produced the normative knowledge on this assignment.

Juana answers back with an argument, stating that she can divide 33 and 3 by the number 3 to reduce the numerator of one fraction and the denominator of the other. The move enacts in public discourse the type of reasoning that Felipe called for, zeroing in on a specific past step and arguing for the veracity of that reasoning. Juana has answered Felipe's call, as she makes public at least some aspect of the reasoning she conducted while looking at the paper. Her argument in

this turn differs from the comments Juana made in her first two turns, where she stated she was correct. In both of those prior cases, Juana stated that she had performed the work correctly without stating how and why. Now, Juana makes evident what types of reasoning lead to her conclusion.

In the exchange so far, Felipe has been working to help Juana realize that she needs to take the reciprocal of the 11/3 fraction. He enacts three epistemic actions: providing testimony, asking Juana to recruit perception, and asking Juana to recruit mathematical reasoning. Juana complies with all three, pausing her work at the tutor's suggestion that something is wrong, preparing her pencil for an act of erasing, looking back at her work, and enacting and then vocalizing her reasoning—deploying reasoning and perception simultaneously. All of these moves are possible because of the distributed configuration of the activity, where the paper has stored Juana's past work for as-needed data about her prior math actions. Nonetheless, these actions fall short of the intended epistemic end. Juana has so far not noticed why her prior work on the problem will lead her to the wrong answer. The epistemic resources have instead reinforced Juana's perception of the veracity of her prior work. Instead of *knowing* what went wrong, Juana *knows* what went right.

After Juana articulates why the math action she was about to perform is accurate, there is a 4 second pause in which SJ and TF look at each other silently before breaking into laughter.

Figure 46: Juana expresses confusion about why Felipe is still looking at her, both participants laugh, and decide that "it got hard."

Felipe's earlier testimony, reinforced again with his long, silent pause after Juana's rebuttal, suggests once again that Juana has taken a mathematical misstep. Juana, who has argued her case, articulates that something has broken down in the strategy the two have taken to correct the mistake: "Why are you looking at me like that?" The question marks a gap between what Juana understands to be correct and what the tutor understands to be wrong, refuses to ignore, and will not reveal. Both participants' bodies shift toward the backs of their chairs, disengaging fleetingly from the activity, as TF says, "alright, alright, alright." In the final two turns, framed in

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the background with laughter, the participants agree that "it got hard." This moment marks one of strategic regrouping, where participants recognize that the work is hard and that the route they have taken so far has failed. In the subsequent exchange, Felipe proposes a new plan for curbing the mistake and he and Juana execute the plan together.

TF: We're gonna- what are we gonna do?
    (3.0)

SJ lifts up her workbook and moves it in front of her body.

SJ: Stop?
TF: Okay, pause, right? Let's work on this together, okay? So something's wrong here.

TF places flat hand covering SJ's work on problem.

TF: Yeah (*directed to other student*). Something's wrong here, right? Right?
SF: (*nodding but looking away*) (3.5)
TF: So we gotta- we gotta find out what it is. So let's start from the beginning, okay?
SJ: Uh huh
TF: So this is the beginning?
    (1.0)
SJ: (*nods*).
TF: So you did this. So: four times eight is thirty-two.
SJ: (*nods*)
TF: Plus one is thirty-three. So that's right. Three times three is nine plus- plus two is eleven over three that's right. Okay so these are ri:ght. So then you went to he:re. So what happened here?

TF points to 11/3.

Figure 47: Felipe endorses Juana's accurate work and asks what happened at a specific moment on the homework.

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Juana agrees to having done *something wrong* on the math problem, albeit somewhat half-heartedly while looking at something in the distance. In simple terms, the tutor's testimony carries weight in the interaction—the tutor is privileged to see an error, withhold describing it, and yet still focus the interaction on resolving it. Repeated statements about what Juana should try differently, and now the question ("Something's wrong here, right?") intended to get Juana to agree that an error exists, embed testimony into the route Juana and Felipe take to the normative knowledge on this problem.

She and Felipe look back at each step she took on the problem. Their series of actions simultaneously combines all three of the first epistemic resources: testimony, perception, and step-by-step reasoning. Felipe enacts a process of checking past math work. Both participants angle their eyes toward the page as Felipe vocalizes each step that Juana took and endorses the veracity of each step. He is specifically laminating testimony on each of Juana's prior steps, anchored by the written work on the page and their present perceptions of that work. The testimony is organized in the form of the step-by-step work that Juana produced earlier, enacting the reasoning that Juana used to arrive at the mistake point.

The epistemic resource of memory is explicitly evoked at the end of this exchange. Felipe asks: "So what happened here?" He gesturally points to a specific moment in Juana's past work and asks her to reflect on the mathematical events that happened there. The action draws in an immediate perceptual experience as well, as Felipe points to the 11/3 fraction on the page. The action further gathers meaning against the frame of the recent step-by-step reasoning through each of Juana's math actions to start the problem. Juana responds with a gestural shrug.

TF: So what happened here?
(4.5)

SJ shrugs after 4.5-seconds of looking at her work.

Figure 48: In response to Felipe's question about what happened at a specific moment, Juana shrugs.

Felipe's tutoring intervention is geared toward Juana generating the insight that she forgot to take the reciprocal. The intervention, thus, is about more than getting the correct math knowledge on the page—it involves Juana creating and tracking her own understanding. The after-school center expects that students satisfy the epistemic end of understanding how to solve the math problem, over and above finishing the homework with the correct answers on the page. Large parts of the exchange prior to the shrug involve exactly this process. Juana moved from stating that her work was correct to agreeing that the work got hard and then that something was wrong. One could even argue that Juana's earlier efforts to argue that her work was "right," in

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the context of the tutor's persistent public testimony that something was "wrong," created in their interaction the reality that Juana did not understand how to reach the normative answer.

Now, in this gestural shrug, Juana again acknowledges that she cannot figure out the mistake. Juana is metacognitively monitoring what she does and does not understand. Introspection—or the process of attending to and describing one's own mental state, in this case the mental state of comprehension—becomes the vehicle through which Juana tracks whether she has achieved the epistemic end of understanding. Juana's reflection on her own cognition becomes a social act at the point that she shrugs. This public capacity to share metacognitive reflections means that the epistemic end of understanding is brought to light between the tutor and student and thus has the capacity to shape the interaction, namely the search for what epistemic resources are needed to move past this lack of understanding (a topic taken up more squarely in the following chapter of this dissertation). The only way for Juana to *know* whether she has reached the epistemic end of understanding is to attend to whether she arrives at the knowledge valued in the community. Juana's ongoing reflection becomes a resource for measuring understanding.

A half-second after Juana shrugs, she says, without any affect or prosodic layering that she needs to take the reciprocal.

SJ: You have to do the reciprocal.

$$8\frac{1}{4} \div 3\frac{2}{3}$$

$$\frac{33}{4} \qquad \frac{11}{3}$$

$$\frac{33}{4} \times \frac{11}{3}$$

SJ points to the 11 and then the 3 in the lower right fraction.
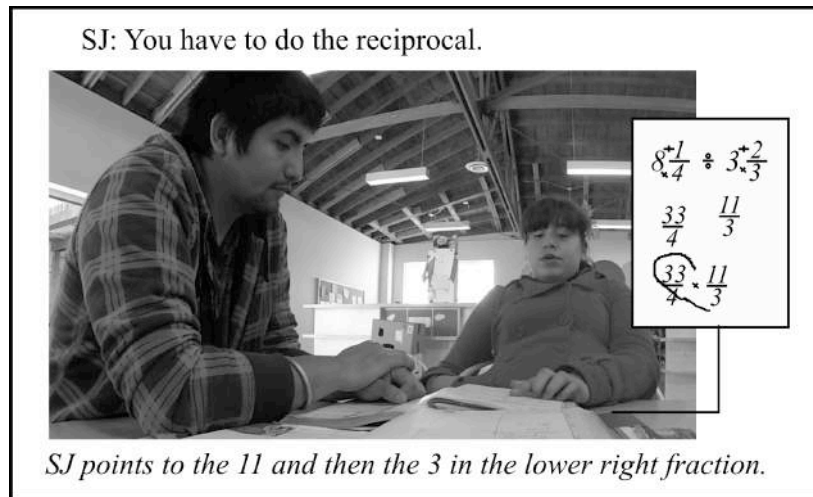
Figure 49: With flat affect, Juana states that, "You have to do the reciprocal."

Because the word reciprocal is not written anywhere around her and because Felipe never provides the idea on his own, the concept comes from Juana's memory. The point at which Juana recalls the idea of a reciprocal from memory cannot be divorced from the prior epistemic resources that carved a specific interactional route toward this moment. We do not need to ask whether Juana could have recalled the forgotten reciprocal without testimony, step-by-step reasoning, and perception. We can acknowledge the origin of the reciprocal idea just in the way we can acknowledge the experiences that give rise to arriving at the destination of a long walk. The tutor's original testimony regarding the mistake caused Juana and Felipe to visually inspect the work, through step-by-step reasoning, which then caused Juana to stop at this exact point in the problem and reflect on what might have gone wrong. These moments combine to create "a route toward cognitive accomplishment," (Solomon, 2007, p. 413), a thread of epistemic actions that leads toward the statement that Juana needs to take the reciprocal.

When Juana vocalizes the idea of a reciprocal, she also grounds the idea back within the perceptual context of her written work. She points to the part on the page where the idea of a reciprocal action matters. The gesture parses the visual field into the two specific numbers

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implicated in performing the reciprocal action, unfolding an abbreviated simulation of how to conduct the reciprocal action. As such, memory, perception, and reasoning become fused within this moment, tying a recollection of a math strategy to a specific visual point in Juana's past work and signaling how that action can be deployed.

Immediately after Juana issues the verbal and gestural reciprocal action, Felipe leans far back in his seat and Juana expresses an elongated, "Oh yeah!"

TF leans back in his chair; when he reaches the back, SJ starts to talk.

SJ: ↑O:::¦::Ohh¦yeah hhh hhh

SJ smiles, TF smiles, and they look at each other.
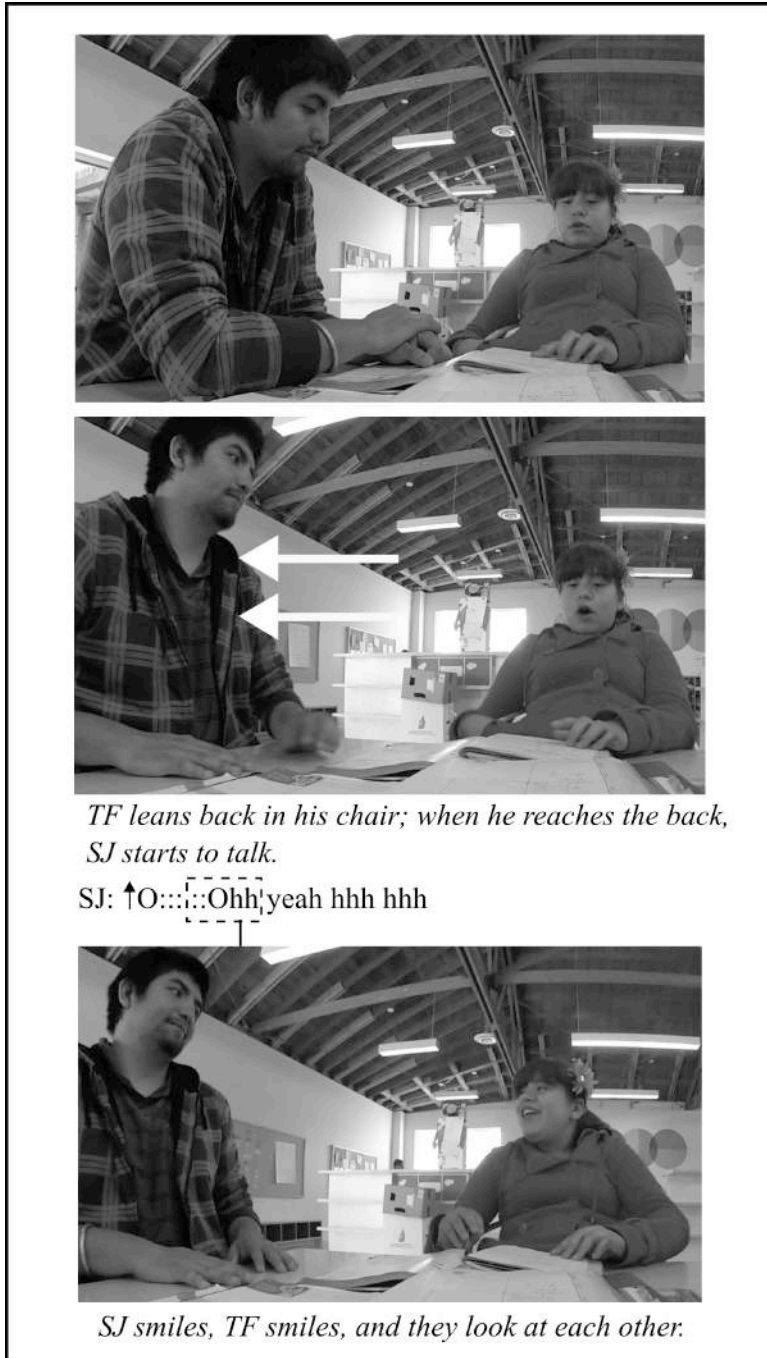
Figure 50: Felipe leans back and smirks as Juana says, "Oh yeah," smiling and looking at Felipe

Felipe's action to lean back disengages his body from the space. He is no longer angling his shoulders over Juana's written work and his face is no longer positioned down toward Juana's written work. With a smile, Felipe suggests that Juana resolved the obstacle. The

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movement and the smile near simultaneously laminate expert testimony on top of Juana's recollection of the reciprocal action.

In addition, Juana articulates a drawn-out "Oh yeah!" alongside her own smile. The verbal phrase marks a second definitive moment in which Juana describes her own mental state. Instead of the shrug marking lack of comprehension, Juana now marks understanding. The "oh yeah" further signals that this is something Juana already knew before, but had seemingly forgotten. These two features of the "oh yeah" mark that this moment is the one in which Juana understands her prior mistake and the normative correction.

Juana succeeds in meeting the epistemic ends of knowledge and understanding. Not only can Juana produce the correct answer on the page, but she also knows that she herself previously understood and now again understands this mathematical action. Taken in context with the shrug that took place 5 seconds earlier, Juana has completed a transformation from a state of not knowing to a state of knowing, and she herself publicly shares her reflection on both epistemic states in the interaction. These displays of comprehension evidence that Juana is tracking her own understanding—introspecting, so to speak—and making that introspection process both public and synchronized with other events.

In the moments after the transcript ends, Juana reasons through what is meant by a reciprocal, flipping the second fraction (11/3) and solving the problem. By the time Juana comes to know the answer to the problem, she and Felipe have laminated the sources of testimony, perception, memory, introspection, and reasoning. The implication of this analysis is that the problem—which Felipe describes with the vague "it got hard"—is dissolved with a complex of sources of knowledge, which if made visible, could be built into both stories of failure and success.

6.6 Summary of interactions between enacted epistemic resources

Two epistemic ends motivate the mathematics tutoring at this after-school program: (1) produce correct math knowledge on the assignment and (2) understand the math knowledge that you produce. I examined one exchange between Felipe, the tutor, and Juana, the student, as they worked to resolve a mistake that Juana made on her math assignment. Drawing on the methods of interaction analysis, I described how the tutor and the student recruited and publicly displayed the use of five sources of knowledge—perception, testimony, reasoning, introspection, and memory—in order to produce the correct math knowledge on the assignment and to ensure that the student understood how to produce that knowledge.

The epistemic route taken by the dyad began with the tutor providing testimony that an aspect of Juana's work was wrong, without the tutor saying what exactly was wrong. The tutor then guided the student to "look at it again" and "follow your steps," each of which prompted Juana to perceptually examine her prior work and consider a subset of the reasoning she enacted on the problem. Juana responded with an argument about what was correct about her work, and in both cases, expressed certainty that the work was correct: "You could do it," and "It's right."

After regrouping, Juana and Felipe then agreed that something was wrong in Juana's work and together enacted the process of following the steps Juana took on the problem. As they looked back on each math action Juana had taken, Felipe laminated his own expert testimony on Juana's written work. Felipe then explicitly invited Juana to draw on her memory of the math actions she took at a specific point on the problem: "So what happened here?" After marking that she did not have an answer, which evidenced Juana's reflection on her own understanding, Juana then stated that she needed to take the reciprocal, pointed to where on the page, and referenced the numbers involved in the reciprocal action. These actions brought together perception,

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reasoning, and memory into a single instance. When Felipe drew his body out of the space and smiled, providing another layer of testimony that Juana's claim was correct, Juana reflected again on how her understanding of the situation had changed: "Oh yeah!" This final spoken comment, understood in the context of Juana's earlier shrug of uncertainty, made public that the correct answer had been found and that Juana understood that action.

This analysis provided a situated description of the enacted epistemic sources of Juana's clam that "You have to do the reciprocal" and of Juana's understanding of that claim. Instead of taking a narrow view of the proximal epistemic resource that took place immediately preceding Juana's claim, I have looked at the epistemic aspects of the interaction that gave rise to the claim. This route consisted of the tutor's constant testimony, the student's visual inspection of her past written work on the problem, the student's reasoning about the veracity of the steps taken, the student's memory of relevant math actions, and the student's metacognitive monitoring of her own understanding, resources that merge together to generate the math claim ("do the reciprocal"), and the accompanying claim that Juana understands these math actions ("Oh yeah!").

6.7   Discussion

I set out to answer the question of how a student at an after-school learning center comes to generate math knowledge and understand that math knowledge. The student's recollection and application of the reciprocal math action represents a pedagogical achievement dependent on the participants' use of a patchwork of knowledge sources in their local environment. Examining the talk, body movements, gestures, and environmental resources that organized the interaction between the math tutor and student, I argued that the process of repairing a mistake on a math problem occurs through interactions that laminate multiple sources of knowledge. Over the

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course of about one minute of interaction, the tutor and the student integrated the resources of memory, perception, reasoning, expert testimony, and the environment into an interaction devoted to creating normative math knowledge.

What becomes evident through this analysis is that knowledge claims have the capacity to conceal the resources that come together in an interaction unless we look closely at the moment-to-moment transformations of talk and body in the environment. I have not been interested in this chapter in whether the claim can be warranted as true justified belief, the standard philosophical pursuit. I have instead focused on the process by which a knowledge claim comes into being and the significant epistemic actions that make it possible. Some research on epistemic actions (e.g. Kastens, Liben, & Agrawal, 2008) has focused on how physical manipulations of the environment "unearth valuable information that is currently unavailable" (Kirsh & Maglio, 1994, p. 515). I observed that a great deal of other actions serve a similar purpose. Drawing on memory, probing with extended eye gaze, reasoning through the order and veracity of math actions, and drawing on expert testimony are all epistemic actions that create a math claim that is unavailable to the student at the start of the exchange. Importantly, these sources of knowledge did not exist as independent generators of insight, but rather, as features successively laminated on each other to build the conditions for making the claim.

The idea of the source or the origin of knowledge is expanded in this analysis. Instead of seeing the final action that precedes the knowledge claim, a recollection from memory, as the sole origin of the reciprocal claim, I have argued that the ritual, practice, or pathway through which participants deploy multiple epistemic resources in the setting carves their route toward the claim. This should not be mistaken for arguing that the student needs all of these past epistemic actions to justify the veracity of the claim that the reciprocal needs to be taken—it may

be that her memory of the reciprocal math action having worked in the past would be enough. But the source of the claim—the originating experiences that gave rise to the claim—fused the resources of an expert commenting on the quality of the student work with the experience of a student looking and recollecting, in addition to following math rules and reflecting on understanding. In a strict sense, the narrow view that memory gave rise to the reciprocal is also correct, but it misses the history of epistemic actions taken to set the stage for that resource—events that are as much the origin of the claim as the memory itself.

How do these results connect with previous work on the notion of knowledge in situated cognition? How can we further theorize about the relation between persons acting and the spaces in which they act? Lave (1988) draws a distinction between the arena—the layout of material and social structures provided in the infrastructure of institutions and which for the most part remains beyond the influence of the individual—and the setting—the personally-experienced, edited version of the arena that constitutes the relation between the goals and actions of the person and the features provided in the arena. In other words, the arena describes the environment and the setting describes the personal pathway experienced by the individual moving through that environment. Repeatedly experienced settings for individuals passing through arenas generate fields for action. Lave's point is that settings are rooted both in the physical design of the environment and in our actions in that environment.

In a similar way, the paper that preserves the student's pencil markings, the presence of tutor, and the table and chairs that organize these resources around one another, present the arena through which the tutor and student generate knowledge. The student's own cognitive resources, and the solicitations to use those resources from the tutor, blend with the setting to amount to a knowledge claim. Because cognition extends into the environments we occupy, knowledge

grows out of the synergy between the resources the environment furnishes and the resources the brain furnishes. To reflect on Hutchins' (2014) ruminations on the center of a distributed cognitive system, it would be shortsighted to say that the idea of taking a reciprocal math action emerges solely from the internal neural hardware of the student. The modular neural hardware that generated the memory of the reciprocal emerged because visual perception continuously refreshed the image of the *external* pencil markings on the page and because an *external participant*, the tutor, reasoned through math steps to find a specific failure point.

In its early stages, this project is not without its shortcomings. First, this approach needs to be expanded to more students within the after-school setting and to learning situations beyond this setting, both within and outside of mathematics. These studies would throw light on how different settings treat the knowledge construction process. How are epistemic resources ordered, when are resources maximally used, when should resources be publicly discussed, and how do answers to these question vary depending on the goals of the learning community and the task demands? Even further, how do different configurations of epistemic resources suppress or encourage student inquiry?

Second, in broadening the idea of a source of knowledge, we face the question of what can be ruled out as a source of knowledge. Do all of the experiences that lead up to the moment of knowing count as a source of knowledge? The question involves causal claims about what produces an action that we consider to be knowledge. Hesslow (1988) speaks eloquently to the issue, noting the complex origins of events:

"Most of those events, facts, states or properties for which causal explanations are appropriate, have infinitely many causes. There are three reasons for this. Firstly, an event will normally depend on the immediately preceding occurrence of several different

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events. Secondly, it will usually be possible, at least in principle, to trace a causal chain backwards in time. Thirdly, it is generally possible to conceptualize the causes in infinitely many different ways…however, when we explain why an event occurs, we never mention more than a few, usually just one, of the events making up this complex web of causal antecedents" (p. 11-12).

If an action such as producing a knowledge claim has infinitely many causes, how do we decide which causal antecedent is the origin? Hesslow (1988) provides a host of criteria that people have used to select the "one most important" cause out of the milieu of causes: the relevant cause can be unexpected, occur just before the outcome, seem abnormal, be used to hold someone responsible, predict future outcomes, be irreplaceable, be controllable, or simply be interesting. Disregarding which of these leads to true or correct ideas, Hesslow points out that when people talk about causes of events, they often have different goals in mind. Depending on whether we want to hold someone accountable for struggling to create knowledge, intervene to help them create knowledge, or predict whether a group of students will create knowledge, we may tell different stories about the sources of knowledge that gave rise to the students' epistemic claims. The value-laden nature in which we select certain experiences, instead of others, to credit for causing knowledge is something that educators and researchers need to consider when reflecting on this topic. The distributed take on knowledge construction in this chapter recognizes the possible stories that could be told about failure; the social layer, which takes into account what is worth learning and how, could guide which stories educators consider productive.

Third, experimental methodologies could be applied to more directly understand how students use the epistemic resources of memory, reasoning, and introspection. This would involve generating sharper classification systems for different types of reasoning, introspection,

and memory, and then studying how uses of these resources shape the knowledge construction process. In addition, experimental methodologies will allow researchers to track how different configurations of these resources produce different types of valued epistemic ends, such as knowledge and understanding. Finally, taking into consideration how students and teachers can think productively about the origins of knowledge would be critical to fostering agency and independence in learning environments.

6.8 Connecting epistemic cognition and stories about failure

In Chapter 7, I conclude this dissertation with a discussion about the connections between epistemic cognition and stories about failure. The heart of the argument is that stories about failure focus on underdeveloped epistemic resources or on connections between epistemic resources. In this chapter, despite that Juana and Felipe skillfully deploy a range of epistemic resources, their reflection on the process presents a rather impoverished account: "it got hard." How would stories that bring to light the moment-to-moment assembly of resource change how students and tutors debug failure and plan interventions?

From an educational perspective, if stories about failure more comprehensively accounted for the resources needed to construct knowledge, then public reflections on failure could uncover effective and parsimonious interventions otherwise unseen in abbreviated accounts of failure. In the coming chapter, I discuss the theoretical connection between epistemic cognition and narratives about failure, practical implications for educators, and future plans for this program of research.

Chapter 7
Discussion and conclusion

The purpose of this concluding chapter is to remark on the theoretical connection between epistemic cognition and narratives about failure, practical implications for pedagogy and learning, and future plans for this program of research.

I have argued that tutors and students during math homework make public a process of constructing obstacles, attributing causes to those obstacles, and intervening to address those obstacles. How participants navigate these processes reveals what they count as failure, who has power to call something failure, what causes failure (and what causes those causes), whose causal theories influence the intervention, how much students control in the intervention, and whether the failure experience is expected to remain stable. These responses to failure occur through public social interaction.

Stories about failure reflect what the learning community believes are relevant resources for constructing knowledge, specifically which of these resources are underdeveloped or underutilized, and which resources should be developed to reach valued learning goals. Failure presents a moment in which the route toward knowledge can be pried apart in public, theorized about, and then used to motivate an intervention. In looking at a single case study, I argued that the route toward a math claim can encompass a diverse array of epistemic resources organized in sequence and simultaneously. Perception, introspection, reasoning, memory, and testimony were fused together in an activity that resulted in a student both performing the normative math action and claiming that she understood how to perform that action.

The integration of these resources on the pathway toward a normative math action presents a complex portrait of the origins of knowledge. The upshot is that when obstacles to math knowledge arise, they mark breakdowns in the local, social contextual configuration of testimony, perception, reasoning, memory, and introspection more so than any context-neutral account of mathematics knowledge. Socially constructed narratives about moments of failure could in turn become infused with this distributed epistemic perspective, accounting for obstacles at a finger-grained perspective and opening up opportunities to shape these (sequences of) epistemic resources.

7.1 Summative implications

I consider the value of this dissertation to be the structures I have described in the failure response process and the questions I have asked about that pubic failure process. Even though I have not provided definitive causal claims, I have described naturalistic practices and formulated prospects for how the aspects of those practices influence one another and connect to valued aims in education. Tutors and students' responses to failure constitute issues of power, statements about students' capacities, statements about what counts as failure and where it comes from, decisions about what students should learn about failure, and attempts to make students more or less independent in resolving failure. These are core issues in any education environment and reflect the broader context in which ideas about causes of failure take shape—a topic that has traditionally been studied outside of routine, goal-directed activity. I hope for this dissertation to be generative, to motivate efforts by educators and researchers to ask questions about their own failure response practices and to study modifications to those practices. The questions that I have raised about timing, granularity, agency, and argument in the processes of defining, blaming, and intervening can provide fuel to evaluate the pedagogy of failure. When

students fail in specific settings, can we come to have a rationale for how we guide social interactions to address who locates the obstacle, how much we describe the obstacle, what we blame, and what we attempt to resolve, including what information we use to make those decisions and whose ideas count? If nothing else, this dissertation issues a call for more attention to the social dynamics of the public handling of failure.

7.2 Epistemic cognition and stories about failure

How can we theorize further about the relationship between epistemic cognition and stories about failure? In Chapter 6, I focused on the epistemic resources that come together for one student to know how to solve a math problem and know that she understands the problem. Thinking about the lamination of memory, introspection, testimony, reasoning, and perception in knowing and understanding, we can reflect on how the failure response process, discussed in Chapters 4 and 5, communicates ideas about epistemic cognition.

In principle, each of the five epistemic resources could play out in the causal search process and in the intervention process. After encountering an obstacle, participants could state that what caused the obstacle were faults in memory, expert support, problem solving, metacognition, or visual distraction, and they could implicate interactions between these resources. Similarly, interventions can focus on strengthening memory, soliciting expert testimony, thinking about math rules, reflecting on one's own understanding, and/or seeking out perceptual information, including attempting new sequences or simultaneous deployments of these resources. Stories about failure become public vehicles for theorizing about which epistemic resources are causally implicated in the inability (however brief) to construct knowledge.

Thinking back on the data in Chapters 4 and 5, we see examples of students and tutors denoting the role of epistemic resources in their narratives about failure. When a student states that the tutor is causing confusion, this observation points out how a *lack of expert testimony* has caused the student's present difficulty with drawing multiplication of fractions. Similarly, some of the interventions point to the role of *reasoning* in the knowing process (e.g. "So there's a couple ways to approach it, right?") and to the role of *perception* (e.g. cases in which tutors and students together visually inspect the student's past work to ground the intervention), and almost all of the interventions involve the tutor's testimony regarding what math/behavioral actions are worth pursuing.

Other causes of failure discussed by participants, such as confusion, do not implicate specific epistemic resources. The causes of confusion did involve specific epistemic resources (e.g. "You're making me confused," which blames the tutor), but not the confusion itself. Is confusion itself a disorienting perceptual experience, a fault in memory, a struggle with imagining/simulating? It may be that the ambiguity of the term is what makes it effective as an attribution of struggle, in the sense that it does not implicate any specific epistemic resources and hence does not guide the participants toward a specific intervention. Similarly, a causal ascription about the difficulty of a math problem does not implicate whether the problem is difficult because of memory, reasoning, perception, or testimony. Because attributions of confusion and difficultly do not implicate specific underdeveloped or absent epistemic resources, participants are more free to unfold the features of those causes over time. We saw examples of confusion tied specifically to an inscription (a negative sign) and to someone else (the tutor's actions), which function as attributions of attributions that more precisely describe the origins of failure.

I also want to draw attention to the causal ascription of ability, skill, or capacity. Ability has been construed as an internal, trait-like quality of an individual. Considering both the epistemic cognition analysis in the prior chapter and the causal reasoning analysis in this chapter, I would argue that these small obstacles count as micro failures in ability. Students in the moment that the obstacle appears are *unable* to produce the normative math or behavioral action. This dissertation calls for educators to reframe the notion of ability in school, to take out the negative connotation involved with it, and to view lack of ability as a warrant to understand and intervene in the learning activity. In a situated account of knowledge, one could still conclude that students' inabilities are stable within a particular situation, possibly because of a lack of external resources or because of institutional norms beyond the influence of the individual. However, what must be recognized is that modifications to that situation—whether in student's internal cognitive resources, the external environment, or both—could destabilize the barrier and open up possibilities for learning. Ability should not by default connote something internal and unchangeable, and schools could make it their mission to act on this proposition to empower students to persist actively when struggling toward valued goals.

In further consideration of the prospect that there are infinite causes of outcomes (Hesslow, 1988), should moments of inability even be ascribed to a single factor or to a holistic individual? When a student working on drawing a model of multiplication of fraction explains, "I suck at this," the statement takes a complex set of causes that stretch across the curriculum, teacher practices, student's energy level, tutor's knowledge, local features of the after school program, and the discourse between the tutor and student and reduces it to the singular cause of "I" the student "sucking" at the activity. Lack of individual skill may of course be one of the epistemic resources involved in the package of causes that constitute inability, but which

individual resource it is (memory, reasoning, perception) and how those individual resources merge with those of the environment and ideas from social others all constitute the moment of struggle. The analysis of epistemic cognition and public causal reasoning in this dissertation warrants adopting a distributed outlook on inability.

Lave (1988) has argued that learning transfer is limited when knowledge moves across different settings. As such, the notion of the stability of causal ascriptions may be another way of talking about transfer. If we consider whether ability is stable across settings that strip away the epistemic resources that gave rise to the ability in the past, then both students' abilities to construct knowledge and the stability of those practices are markers of the environment as much as the student. Lastly, how controllable the ability is would also be expected to unfold as a function of the distributed resources that constitute the skill. Whether the student can intervene to change his/her ability would in part depend on how much control they have over the resources that matter in their activity. Whether the student can always ask a tutor, whether a student can always use paper, and whether a student can maintain intact memories would influence whether the student can control the expression of her ability to solve math problems.

The dimension of controllability in attribution theory has traditionally referred to control over singular causes, such as effort or ability. Can students alter their own levels of effort and ability? This concept takes on new meaning in interactional accounts of failure and epistemic cognition. After a moment of failure, tutors and students need to take control over some aspect of the activity to resolve the obstacle. We saw situations in which these interventions targeted the causal ascriptions participants formulated earlier, but we also saw situations in which interventions ignored earlier-proposed causal ascriptions. Controllability, in this way, need not refer to control over the causes of the obstacle, but rather, control over some set of epistemic

actions needed to reach the valued outcome. How actions are divided across participants marks an additional layer of what students control to resolve the obstacle.

7.3 Educational implications

In this dissertation, I presented many possible implications of variations to the aspects of the failure response process. When participants locate the obstacle and how precisely they describe it may determine whether students have to invest time in recognizing and resolving the obstacle before searching for causes, and long delays may place a larger burden on memory or technologies to recreate the conditions in the past that generated the obstacle. Because students and tutors generate contrasting versions of what caused their obstacles, the factors determining which narratives stick, and hence who is responsible for deploying time and effort to intervene, may include issues of power and the availability of resources.

One of the purposes of this analysis is to bring onto the social plane traditionally individualistic theories about attributions of failure. The result is the recognition that attributions of failure play a part in a much larger complex of experience surrounding failure. How tutors and students construct obstacles—including who finds the obstacle, when, and whether students have attempted the obstacle—and how the upcoming intervention involves someone needing to change to resolve the obstacle both function as influences on the attribution search process. That tutors and students bother to reflect on the recent past to understand the historical causes of their failures means that attributions of failure are doing some type of work, whether assigning responsibility or guiding the intervention. Because stories about failure are constructed in the open and between participants, we can ask educators to reflect on these practices to inform more productive storytelling.

How can this framework and analysis guide more productive practices in mathematics education? I have intentionally held back from suggesting that some of these failure response practices are more effective than others in fostering high-quality learning. In the nascent stages of this qualitative work, it would have been limiting to settle on a few parameters, manipulate them in a controlled space, and offer causal or correlational claims. With more qualitative observations, a broader sample of students, studies of failure in different contexts, and controlled experimentation that takes into account learning gains, we can then begin to explore how variations in the failure response process create better or worse conditions for learning. For now, I present a series of questions that educators can use to help reflect on their own teaching practice. The following questions are meant to be conversation starters among teachers and pointers to re-think what may have become stable, transparent practices in school. In broad strokes, all of these possible interventions focus on fostering in students counter-narratives about failure (Berry, Thunder, & McClain, 2011) that supplant staid ideas about fixed inability with more nuanced stories that promote actionable strategies.

The first set of questions that I raise focus on the obstacle description process: Who finds the obstacle, what do participants count as an obstacle, and what have students tried at the point that the obstacle becomes known as such? To foster student agency in mathematics and give students mastery in self-correcting, one goal in an educational environment may be to shift the obstacle-finding process over to students. When is it appropriate in the learning process for students to notice obstacles to progress and when is it appropriate for teachers to notice obstacles to progress, and how do answers to these questions reflect different assumptions about the purpose of learning in the target environment? Both of the students who constructed an obstacle out of not knowing how to proceed on a math problem blamed their own states of confusion. If

this pattern generalized to other students' attributions of inaction, then it would raise the challenge of not only helping students find obstacles but also teaching students to formulate productive accounts of struggle. The causal ascription of confusion may offer the right amount of vague description for participants to explore lots of alternatives in some settings, but more precise accounts could also motivate specific interventions.

In light of transformative research on the productivity of failure (Kapur, 2008), how can educators start to reflect on which learning obstacles should be classified as problematic and which should be understood as generative, powerful, and essential moments in the learning process? Framing an action as an obstacle and intervening to push beyond it may deny the student the chance to experience ways of thinking that are helpful to long-term understanding. Because participants will pour energy into resolving obstacles, it is critical to figure out what should count as an obstacle, and when, in the context of the goals of the local community and knowledge of the learning process.

Moreover, if teachers and students act to resolve obstacles, but not their underlying causes, then the obstacle may go on repeating. The causes would then become the real obstacle. The math actions recognized as problematic may be the signs of more robust and problematic causes. What other actions can we start describing as obstacles, over and above moments of uncertainty on a math problem, that will better set students up for productive failure? And how does the timing in which obstacles are recognized and the granularity in which they are described open up different possibilities for debugging the etiology of the obstacle?

The second set of questions focus on the causal search process. In some respects, this process is the most important. Doctors prescribe medications when they have the etiology of the ailment understood; car mechanics make adjustments to a car's engine when they understand

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what is causing its breakdown. In the same way, teachers can intervene when they understand why students have experienced an obstacle during homework. The possible causes of moments of failure, and hence points of intervention, can be understood in a distributed cognition framework to stretch back into the cultural history of the community, norms of institutions, the teacher's lesson, and on through student's internal cognitive experiences. Because multiple causes often combine to influence an outcome and because each of these causes have causes extending back into history, it is no small task to comprehensively account for the origins of any failure moment.

Because of the way the causal search process so directly informs the intervention, it is important to diagnose the correct causes of the struggle. In education research, there has been a long tradition of focusing on two specific causes of struggle in math: ability and effort (Weiner, 1983). Even from the small data set in this dissertation, we can see that participants attribute a much greater number of factors to their struggles, including confusion, specific math symbols, friends with food, and tutors. The most relevant question to ask at this stage is: How can we make the causal search process more accurate? Can we slow down the causal search process? Teachers could develop a mindset of empathetic listening coupled with the goal of giving students agency in diagnosing their struggles (Foster, 2014) as a way to extend the causal search process. Combined with a recognition of the situated route toward knowledge, moving slowly and empathically through the causal search process would give participants a wealth of options to consider in how they formulate the etiology of the obstacle and plan an intervention. It may be that schools that stress grit as the default causal ascription of failure prematurely end the search for other sustainable and actionable causes, and send the message that students are solely

responsible for their shortcomings. This call to burrow down to more precise diagnoses of failure actually marks a natural and productive process (Vallacher & Wegner, 1985).

How can we foster honesty in this stage, especially when those involved are aware that the agreed-upon cause will determine who needs to work and how during the intervention? Research that supports a culture of caring in school (Cooper & Chickwe, 2012), in which teachers develop meaningful relationships with students, could be essential to an open and honest inquiry into these topics. How can we honor the complexity and difficulty of the causal search process, and recognize the inherent difficulty of piecing together a story of why a particular problem has emerged out of the historically distal and proximal, and innumerable, causes that actually gave rise to the moment? Because students' identities are "products of a collective storytelling" (Sfard & Prusak, 2005) and under constant negotiation (Fields & Enyedy, 2013; Martin, 2000), we must carefully consider how teachers and students' co-constructed narratives about failure can promote designated identities that align with the goals of the education community.

A situated description of epistemic cognition broadens the approach educational researchers have taken to studying students' ideas about knowledge. The field of personal epistemology has traditionally been concerned with students' professed thoughts about knowledge, in other words, what students say when asked about their idea of where knowledge comes from. A separate line of inquiry has examined students' enacted epistemic cognition, or how students treat knowledge in the course of learning activities (e.g. Louca et al., 2004). For example, epistemic cognition researchers in education can be interested not just in what students believe to be knowledge and whether these descriptions form holistic beliefs, domain-specific beliefs, or fine-grained resources, but also in how students exhibit implicit forms of epistemic

cognition in learning activities. The present study falls squarely in the tradition of the later enacted approach but is not without implications for the former.

For example, this study suggests the possibility for educators to have discussions with students about the interactive character of sources of knowledge in learning, at once making more apparent and honoring students' routine knowledge practices for the purpose of explicit reflection. In addition, if knowledge claims emerge as a synthesis between sources of knowledge, then what support and guidance should educators give to students as they explicitly plan their own learning activities and learning goals? Moreover, given the speed with which interaction laminates so many resources, would it even be productive to focus on these micro details explicitly with students? Finally, when we try to understand students' thoughts about knowledge, researchers could present students with scenarios that offer various configurations of sources of knowledge (as Chinn et al., 2011 suggest). For example, instead of asking a math student whether math comes from personal experience or from expert testimony, we could ask whether math knowledge comes in part from seeing, in part from drawing on memory, in part from reasoning, and in part from expert testimony? More importantly, do students weigh each of these sources as having different degrees of credibility and how do students judge the veracity of claims that emerge from different types of interactions between these sources (questions about justifying claims)? The field's understanding of students' post-hoc reflections on epistemic cognition has been colored by simplified versions of sources of knowledge. The link between the way we treat knowledge in interaction and how we reflect on knowledge in post-hoc settings could change provided a situated framework of epistemic cognition.

7.4 Future research and limitations

There are five areas of inquiry that would be worth pursuing in light of this research and which I anticipate will result in modifications to the theoretical framework presented in this dissertation. First, in light of Gunderson, Ramirez, Levine, & Beilock's (2012) call to "further elucidate the mechanisms of math attitude transmission" (p. 162), we need to document whether and how moment-to-moment narratives about failure stick in students' minds and constitute parts of their identities? Do stories repeat and at what frequency, and how do small interactional responses to failure amount to post hoc failure narratives? Answering these questions will involve comparing students' post hoc reflections on failure and identity with their active responses to present failure.

Second, understanding how these stories evolve over time and across math situations will point to their context specificity and start to hint at the variation in practice that can shift students' thoughts about failure. A design-research intervention in which teachers, researchers, and students work together to shift their stories about failure would provide a sense of how possible it is to change norms around failure and move productive failure stories across settings. Combining this question with the first, it bears fleshing out how shifts in interactional practices over time correlate with shifts in post hoc failure stories.

Third, studying stories about failure and epistemic cognition in domains outside of mathematics (and in different mathematics settings) will provide productive templates for social responses to failure that could inform education practice. Looking at Table 1 from Chapter 5, we can see that students and tutors generate what we might think of as a grammar of failure. Would other settings, such as sports or vocational environments, have completely different grammars? Would coaches or managers ever hold back from revealing the obstacle to the learner, more

strictly resist learners' attributions of their own failures, and place a stronger emphasis on designing interventions to help students avoid repeating mistakes?

Fourth, we should begin to study how different failure stories correlate with learning outcomes, especially in design-research projects embedded in school contexts. Carefully tracking learning could indicate the productivity of failure stories and the sustainability of failure interventions, cluing educators in to what types of stories in specific situations are productive. Finally, with a growing sense of which social practices around failure lead to productive stories about failure, we should refine the process of learning how to work with teachers and students to foster these practices.

This dissertation study is not without its limitations. First, the sample size is small and means that these analyses do not capture all of the variation around failure within the after-school setting, let alone outside of the setting. Second, the analysis also focuses more on the structural pieces of the interaction (e.g. who finds failure, when failure is found) than on the lived experience of failure for students in those settings. The interaction analysis approach here is used to locate relevant parts of the failure response process, but not to provide in-depth case studies of how participants shift their practices across time and settings. Third, this work departs from two central theories in educational psychology, attribution theory and personal epistemology. Other theoretical frameworks used to inform theses interaction analyses may have yielded different results.

7.5 Conclusion

Responses to failure do not happen solely within the boundaries of an individual's internal cognitive system. Tutors and students make failure public and relevant during learning-oriented activities as a way to work together to understand how failure comes about and what they can do

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to resolve it. Accounts of the variation and lamination of resources for constructing knowledge help us recognize that these stories about failure could take new forms, breaking through oversimplified accounts of inability and lack of effort, and focusing on comprehensive accounts of how multiple layers of events cause failure. Recognizing that these stories about failure drive how we deploy energy under limited time constraints—and mark contested spaces in interaction—provides a charge to researchers and educators to learn how to use stories as vehicles to empower students to productively persist through failure.

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