

Designing, Implementing and Analyzing a Responsive Teaching Professional Development
for Biology Graduate Student Teaching Assistants

A dissertation by

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Abstract

Responsive teaching is an approach to instruction that foregrounds listening for, attending to and engaging with student disciplinary thinking and ideas in the classroom. This style of teaching differs from how many traditional STEM classes are taught, especially at the college level. Entry-level college science courses that are taught by graduate student teaching assistants more typically feature direct instruction centered on canonical facts or procedures. Considering research that shows the substantial benefits of responsive teaching to student participation, learning, and engagement with content, we designed a professional development course specifically for graduate student teaching assistants in biology to expose them to responsive pedagogy and encourage them to teach more responsively. This dissertation will detail the design and implementation of the professional development. Additionally, I will present the results of three studies conducted in the context of the professional development. Specifically, Study One focuses on reports of noticing and responding in teaching assistants' written journals. I will show evidence that TAs not only noticed student thinking frequently, but also reported on their interpretations and responses to that thinking in ways that valued the substance of student ideas. Study Two is a case study that reveals how one teaching assistant appeared to take up some of the principles of responsive teaching and incorporate them into her sense of what it means to teach. In this study, I will show evidence that one TA was able to take productive seeds of responsiveness present in her beliefs about teaching and operationalize those seeds into a responsive approach to student thinking. Study Three is an analysis of discussions that took place in the professional development itself that informed our understanding of how TAs were framing moments of student thinking. I will show evidence that TAs applied different frames in

different moments but were consistently focused on the substance of student ideas. All in all, the three studies contribute to understanding how our responsive teaching professional development impacted the teaching assistants' beliefs about and practices in teaching.

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Introduction

I. Do humans or bacteria have a higher mutation rate?

This was the question posed to undergraduate students at the beginning of an introductory biology laboratory (BIO14). The lab component of this ‘Organisms and Population Biology’ course had the stated goal of getting students to “do science, not just learn about it” (course syllabus). Taught by biology graduate student teaching assistants (TAs) and undergraduate learning assistants (LAs), the laboratory curriculum was designed with the intention of engaging students in authentic aspects of science like experimental design, data collection, data interpretation and presentation of results. Introducing study systems (in this case, *E. coli* bacteria) with questions like the one above was a strategy intended to generate student discussion that would motivate the formulation of questions and ideas that could be taken up in lab investigations. Such discussions often resulted in a wide variety of student ideas; sometimes their ideas clearly reflected canonically correct topical knowledge, but at other times their ideas were harder to interpret within the context of standard biology knowledge. In addition, students were given space to develop research questions and to design experiments to test those questions without being restricted by pre-determined experiments and protocols. This more open-ended curriculum meant that unanticipated ideas came up frequently in lab each week. Deciding what to do in these moments presented a challenge for lab instructors, the TAs.

To illustrate this challenge, we consider a specific instance in which the above question about comparing mutation rates between species led to a moment in which a student voiced an idea that was unclear, creating a scenario in which the TA was confronted with a decision about how to handle that lack of clarity. In response to the question, Nick (an undergraduate student in

the lab), stated his support for the claim that humans have a higher mutation rate than *E. coli* bacteria. In trying to justify this claim, Nick asked the TA whether “mutation rate include[s] silent mutations that occur in, like, non-coding regions of DNA?” Nick’s question created a moment in which the TA needed to decide, on the spot, how to respond.

In preparation for leading a discussion that stemmed from this question about comparative mutation rates between species, TAs were guided by a supervisor in a lab prep session to anticipate student ideas about relative genome size and generation time differences between organisms. The idea of silent mutations and the relevance of this idea to comparative mutation rates was not discussed during the prep session. When Nick asked his question about silent mutations, it was conceivable (and perhaps even likely) that a TA might feel pressure to *answer* the question being posed by the student with a simple “yes” or “no.” After all, this question does have a binary answer: the mutation rates provided to the class at the end of this discussion (from Lynch, 2010) *did* account for silent mutations (changes in DNA sequence that do not alter protein structure and thus have no observable phenotypic effects). This information was accessible to the TA and could have been used in this situation to answer Nick’s question.

When Nick asked his question about silent mutations, his reasoning behind the question was not yet clear. Did Nick think that some species have higher rates of silent mutation than others? Did he wonder if silent mutations would somehow skew the data away from his initial expectation? Or was he simply bringing up a concept that he was aware of, and wondering aloud if it was related to the question at hand? In a move that ultimately drew out more of Nick’s thinking, the TA asked Nick a simple question: “Why do you ask?” By making the move of asking Nick to “say more” about his idea (i.e., Duckworth, 2006), the TA communicated an interest in Nick’s thinking about silent mutations without providing his own interpretation of what Nick intended.

By asking Nick to elaborate, the TA in the scenario was indicating to Nick that he noticed the presence of an idea, and that that idea required more space for explanation. Nick obliged this request by explicating further on his reason for asking about silent mutations:

Because...well I guess if you're comparing *E. coli* to, uh, humans, most of the *E. coli*'s DNA codes for something whereas in humans, a really big amount of it doesn't. And if it's something that, like if there's an error in *E. coli*, it's generally gonna be in a coding region and it could be something that prevents it from, like, living. Or even be important, like, it could die like right away whereas, uh, I guess if the same mutation occurred in a human, it wouldn't even notice.

As Nick provided his elaboration, it became clearer that he was relating the idea of silent mutations back to his original goal of trying to justify the higher mutation rate of humans as compared to *E. coli*. Upon being prompted to elaborate, Nick indicated that he thought most mutations that happen in *E. coli* will alter proteins (“...generally gonna be in a coding region...”), and could be lethal to the bacteria (“...prevents it from...living...”). Comparatively, Nick explained, many analogous mutations in humans would have no effect (“...wouldn't even notice.”) because of the larger amount of non-coding DNA in a human (“...a really big amount of [human DNA] doesn't [code for anything].”). Nick's idea seemed to be that the larger proportion of silent mutations in humans accounts for the higher overall mutation rate in that species compared to a bacterial species like *E. coli* which experiences mostly phenotypically impactful mutations.

By asking Nick why he was asking about silent mutations, the TA gave him space to discuss his follow-up ideas about the relative amounts of non-coding DNA between species, the potential for deleterious and lethal mutations and the notion of comparing mutation types and rates across species. Nick's thinking could have been further interrogated following this initial exchange by either the instructor or other students in the class:

- *Does Nick consider only non-coding DNA mutations to be silent?*
- *What about silent point mutations in coding DNA that stem from redundancy in the genetic code?*
- *How frequently does Nick think non-silent mutations become lethal?*
- *How does this explanation for comparative mutation rates substantively differ from one that simply suggests humans mutate more because they have more DNA than *E. coli*?*

In this instance, the TA did not ask any of these questions or push the class to further investigate Nick's idea. Instead, the TA moved on to other ideas that other students had about the original question, perhaps indicating that he was satisfied with Nick's explanation. Moving on to other ideas could also simply be indicative of the TA being conscious of time constraints in the lab or even a desire to create classroom equity in terms of sharing ideas. It is not clear if asking any or all of these follow up questions would have allowed Nick to build on his idea by making it more detailed or detracted from it by getting further away from his original argument. The key here is that the TA's initial response to Nick's idea, and Nick's resulting willingness to elaborate, can be viewed as the start of the development of a classroom culture in which student ideas are not immediately evaluated for correctness but instead are elevated to be the very substance of discussion. Inquiry-based classrooms that establish this dynamic between teacher and student have shown the potential for students to feel more comfortable interrogating concepts to a deeper conceptual level (Hammer, Goldberg & Fargason, 2012; Maskiewicz & Winters, 2012).

In order to create the possibility for more moments like these in lab, we became interested in designing ways to encourage TAs to focus their instruction on student ideas and thinking, ultimately designing a course on responsive teaching for TAs. Below, we elaborate on

responsive teaching instruction, summarizing how it can benefit students and how it can be challenging for instructors.

II. What is Responsive Teaching?

Responsive teaching is an approach to instruction that focuses on ways in which teachers can interact with student thinking and ideas. Specifically, responsive teaching emphasizes the elicitation and recognition of student ideas and tasks teachers with noticing, attending to and responding to the disciplinary substance of those ideas (Robertson, Scherr & Hammer, 2015). In the anecdote above, Nick's idea provides a good example of what is meant by "disciplinary substance". Nick's idea has disciplinary substance because he is engaged with trying to think through a biological phenomenon.

We note that in this example, the disciplinary substance of Nick's idea was near the surface. That is, it did not take much prompting to get Nick to dive deeper into the biological thinking behind his idea. Responsive teaching becomes even more powerful when it can draw out substantive ideas that are less immediately obvious than Nick's. Ultimately, disciplinarily ideas articulated by students need not even be canonically correct to carry substance – substance that can be a valuable fabric of a responsively taught classroom (e.g., Ball, 1993).

III. Benefits of Responsive Teaching

In a responsively taught classroom, students are encouraged to feel that their disciplinary ideas and the ideas of their peers have intellectual merit (Ball, 1993; Hammer, 1997; Warren et al., 2001; Maskiewicz & Winters, 2012). The way a teacher attends to and responds to student ideas can influence the classroom culture and norms in a way that impacts future participation – both in terms of equity of participation and the overall disciplinary quality of students'

contributions (Ball 1993; Hammer 1997; Levin & Richards, 2011; Maskiewicz & Winters 2012; Rosenberg, Phelan & Hammer, 2006; Warren et al., 2001).

An example of responsive teaching that elucidates these two benefits of a responsive pedagogical approach – increased student comfort with sharing ideas and enhanced quality and depth of disciplinary discussion – can be found in Deborah Ball’s (1993) paper on elementary math instruction. Ball (1993) details an instance in which one of her students made the claim that the number six is ‘both even and odd.’ Despite this notion being canonically incorrect, Ball (1993) allowed the student to explicate his thinking and gave space for other students in the class to critique and refine the idea. Ultimately, by listening for and attending to student ideas, Ball (1993) created a classroom environment that made students feel comfortable (and in some cases, even eager) to share their own thinking and ideas and to critique those of other students.

The class had been working on developing an understanding of even and odd numbers when a student in the class, Sean, offered a unique idea: “Sean announced that he had been thinking that six could be both odd and even because it was made of ‘three twos’” (Ball, 1993). Even though Sean’s idea of a number that can be both even and odd because of its factorial composition is canonically incorrect, the comfort that Sean had with sharing his creative idea with the class is a consistent outcome in responsively taught classes (Coffey, Hammer, Levin & Grant, 2011; Engle & Conant, 2002; Hammer, 1997; Hammer, Goldberg & Fargason, 2012; Manz, 2015; Maskiewicz & Winters, 2012). Consistently responding to the substance of student thinking and pushing on that thinking – rather than simply evaluating student ideas for right or wrong-ness – helped Ball (1993) create a classroom culture that allowed and encouraged students to articulate ideas (like Sean’s) without fear of embarrassment or rebuke.

We intended to train our TAs in similar practices so that they could begin to facilitate student comfort with generating, sharing and considering ideas in the face of lacking disciplinary

expertise. The way the TA responded to Nick's question about silent mutations is a good example of an early move by the teacher to position student ideas as both important and worthy of further exploration. Continued and concerted effort on the part of the instructor to position student thinking in this way can help facilitate the willingness and eagerness of students to share their ideas that was seen in Deborah Ball's classroom with Sean (1993).

One move that Ball (1993) made in her initial response to Sean's idea about even and odd numbers, was to point out an idea that another student had previously brought up: "I called attention to what I referred to as 'Ofala's definition for odd numbers,' which she restated as 'an odd number is something that has one left.'" Following Ball's juxtaposition of these ideas, the students in the class began interrogating Sean's proposed idea with follow up questions. The disciplinary nature of students holding each other accountable for the intellectual and practical merit of their ideas is another observable outcome that often stems from responsive teaching practices (Hammer, 1997; Hammer & Van Zee, 2006; Levin & Richards, 2011; Robertson, Scherr & Hammer, 2015).

One student in particular, Mei, worked hard to both understand Sean's idea about even and odd numbers and to refute it with her own understanding. The section of transcript below from Ball's (1993) paper beautifully illustrates the student-student interactions that Ball's responsiveness helped elicit.

Mei: I think I know what he is saying...is that it's, see. I think what he's saying is that you have three groups of two. And three is an odd number so six can be an odd number and an even number.

Teacher: Is that what you are saying, Sean?

Sean: Yeah.

Mei: Then why don't you call other numbers an odd number and an even number? What about ten? Why don't you call ten an even and an odd number?

Sean: (paused, studying her drawing calmly and carefully) I didn't think of it that way. Thank you for bringing it up, and I agree. I say ten can be odd or even.

Mei: (with some agitation) What about other numbers? Like, if you keep on going on like that and you say that other numbers are odd and even, maybe we'll end up with all numbers are odd and even! Then it won't make sense that all numbers should be odd and even, because if all numbers were odd and even, we wouldn't be even having this discussion!

The interrogation of Sean's idea that Mei engages in by interpreting, questioning and applying Sean's thinking to other examples is remarkable in its disciplinary substance. Mei is engaging in mathematical thinking and practice through her attempt to make sense of, and ultimately disagree with, Sean's explanation of evens and odds. Disciplinary argumentation between students, like what occurs between Mei and Sean above, is a product of Ball's techniques of positioning students as the owners of their ideas. By giving Sean agency over his idea, Ball implicitly gave the other students in the class agency over their own ideas. Mei took advantage of this culture to interrogate Sean's idea and inject her own thinking into the discussion.

The willingness by both Sean and Mei to engage in this depth of discussion of a disciplinary idea is in line with the type of topical discussions we hoped our TAs would work to elicit in their teaching labs. In the Nick example above, the TA posed a question that not only granted Nick space for elaboration, but also made his thinking visible to his peers (and potentially available for interrogation). By training our TAs to practice attending to student thinking and responding in ways that position the students as owners of ideas, we expected to begin to see the emergence of similar kinds of substantive discussions in the labs.

IV. Challenges of Responsive Teaching

While the benefits of responsive teaching for students are seen in their increased willingness to give voice to ideas and enhanced ability to engage in disciplinary argumentation, there are challenges of this style of instruction for teachers. The components of responsive teaching – noticing, attending to and responding to student ideas – all carry potential challenges for instructors. Distractions can limit noticing, epistemological beliefs about teaching can interfere with attention, and concerns about non-standard knowledge being taken up can influence response. Teachers may not even perceive their role as one that requires noticing and attending to student thinking. Even a teacher who does subscribe to a more responsive pedagogical approach may find that noticing the presence of a student idea can be more challenging than it might seem. Teachers may be distracted away from noticing student ideas by student behaviors, time constraints, procedural demands or a variety of other simultaneous things going on in a classroom at any given time (see Schoenfeld, 1988).

Students also rarely articulate ideas with an announcement that they are doing so. It can be easy for a teacher to overlook or fail to identify a student idea that is articulated off-handedly or quietly. Even if a teacher successfully notices and identifies the presence of a student idea, figuring out what the idea means can be an added challenge of responsive teaching. As elaborated on by Ball (1993), getting at the substance of student thinking is an instructional technique that requires practice and intentionality on the part of the teacher to not simply judge ideas for canonical correctness (Ball, 1993; Coffey, Levin, Hammer & Grant, 2011; Hammer, 1997; Hammer, Goldberg & Fargason, 2012; Rosenberg, Phelan & Hammer, 2006).

Noticing the disciplinary potential in ideas, particularly those that are not completely correct may be difficult, or perhaps even unfamiliar, for novice teachers like TAs. Goertzen, Scherr & Elby (2010) studied the underlying beliefs that physics TAs had that caused them to

focus largely on the canonical correctness of student ideas. The TAs in their study tended to focus on indicators in student speech and writing that suggested whether or not students understood concepts (i.e., looking for the use of particular keywords) (Goertzen, Scherr & Elby, 2010). One of the TAs in this study, Julian, believed that one of his primary responsibilities as a teacher was to guide his students towards an “instructionally targeted answer” (Goertzen, Scherr & Elby, 2010). While there can be value in providing this kind of guidance to students, the researchers found that when students were talking with Julian about physics concepts, “Julian’s attention [was] on the precise wording that he expects in the correct answer” (Goertzen, Scherr & Elby, 2010, p. 11). This level of focus on exact, specific instructionally-targeted correctness often led Julian to miss out on attending to the thinking behind a student articulation, thinking that sometimes was very well-aligned with traditionally accepted disciplinary knowledge (Goertzen, Scherr & Elby, 2010).

If the epistemological belief about the role of a teacher being to guide students towards a particular, “right,” answer is widely held among TAs, it could prove to be a challenge to overcome. The pressure TAs might feel to listen for and notice the canonical correctness (or incorrectness) of student ideas likely comes from their own experiences as students rather than their current positions as researchers. This tendency for teachers to teach the way they were taught is referred to by Dan Lortie (1975) as “the apprenticeship of observation.” While TAs are actively engaged in science in their own research in ways that likely include disciplinary uncertainty and expression and discussion of novel ideas, their experiences as students likely included classes in which the teachers distributed the knowledge and the students received it.

The presence of accepted disciplinary knowledge and its potential misalignment with student ideas represents another challenge associated with responsive teaching: knowing how to respond when this mismatch arises. Traditionally positioned as topical experts, teachers may feel

pressure to give specific, fact-based information to their students. STEM disciplines are often well-rooted in accepted ‘knowledge’ and ways of thinking. Prior to her analysis of moments from her class, Ball (1993) writes very transparently about this consideration for a teacher:

So, even when the teacher hears the child, what is she supposed to do? What does it mean to respect children's thinking while working in a specialized domain that has accepted ways of reasoning and working and accepted knowledge (Kitcher, 1984)?

An example of this challenge arose in Ball’s class when Sean proposed his idea about the number six being both even and odd. Sean’s idea was canonically incorrect and certainly not in line with the accepted definitions in mathematics. A teacher unconcerned with creating a responsive classroom environment might have moved to simply correct Sean and impart to him the “accepted knowledge” about evens and odds. Straying too far from accepted disciplinary ways of thinking carries the potential risk of propagating nonstandard knowledge that might be confusing or hard to parse out for students who are not yet experts in the field. This challenge associated with responsive teaching may have been the motivation for the TA in the Nick example to stop interrogating the idea on the table after the initial inquiry. Pushing for more consideration of the idea of silent mutations in that context could have run the risk of generating discussion that was several degrees removed from the original point. Taking an idea brought up by the student in the moment and deciding whether to explore it or not – especially if it is an idea grounded in convoluted or nonstandard reasoning – is challenging!

Ball (1993) writes about this challenge, saying: “Sean noticed that some even numbers have an odd number of groups of two. Hence, they were, to him, special. I thought about how I could treat this as a mathematical invention – and whether I should.” Through her attention to the substance of Sean’s idea and also to the uniqueness of his thinking, Ball recognized that the idea was important and personal to Sean. In deciding to give Sean agency over the idea and

space to explain his thinking further, Ball (1993) opened the class up to the risk noted above.

That is, the class could have potentially taken up Sean's idea and pursued a nonstandard way of thinking about a basic mathematical concept. Ball (1993) writes about this challenge in her teaching journal after Sean first proposed his idea:

I'm wondering if I should introduce to the class the idea that Sean has identified (discovered) a new category of numbers--those that have the property he has noted. We could name them after him. Or maybe this is silly--will just confuse them since it's nonstandard knowledge-- i.e., not part of the wider mathematical community's shared knowledge. I have to think about this. [Teaching journal, January 19, 1990, pp. 184-185]

Ball's articulation of her uncertainty about how to handle Sean's nonstandard idea is a representation of one of the challenges associated with responsive teaching: different response types carry different potential benefits and risks (Hammer, 1997). On the one hand, the potential for the nonstandard knowledge being offered up by Sean to confuse the class existed. The class discussion of Sean's idea could have devolved into unclear descriptions of and questions about a theory that at its core was canonically incorrect. On the other hand, by responding in a way that gave Sean agency and ownership over his idea, Ball helped contribute to the classroom culture that made students feel comfortable voicing ideas. In fact, by responding in this way, Ball created conditions that allowed for genuine discourse between students that led to some in-depth interrogation of Sean's idea.

While having a feel for the students in the class can help a teacher make decisions about how to handle ideas like Sean's (or Nick's), knowing for sure what direction the class will take such an idea is impossible. The challenge of making decisions about how to respond to disciplinarily nonstandard ideas from students leaves the instructor to grapple with this uncertainty in the moment.

Despite the challenges for teachers associated with responsive teaching, the benefits of for students drove us to develop a professional development for our TAs that was aimed at helping them create a responsive classroom culture that valued, elevated and built upon student ideas and thinking.

V. *Resources TAs can Apply*

While the challenges outlined above can make responsive teaching daunting and difficult for teachers of all experience levels, there is some evidence that TAs already have some resources that may prove useful for developing a more responsive pedagogical approach. For instance, Schussler et al (2008) conducted a biology education seminar with graduate student teaching assistants in which the TAs were given opportunities to reflect on their own teaching practices in both writing and discussion. This reflective seminar helped seven TAs develop insight into teaching practices as well as discover the value of reflective discussion (Schussler et al., 2008).

Schussler et al (2008) noted that TAs in the seminar showed a willingness to question traditional teaching approaches and an openness to considering alternative practices. A TA who partook in the seminar noted: “I was assuming that all of my classes would be teacher-centered and lecture-based. This class introduced me to a multitude of alternate methods that can be applied to classes I teach in the future, even the largest enrollment, entry-level freshmen classes” (Schussler et al., 2008, p. 34).

While the commitment to the canon that Julian showed in Goertzen, Scherr & Elby’s (2010) study represents a challenge for novice instructors with respect to attending to the potential of student ideas, the self-introspection and willingness to challenge traditional instructional methods that TAs showed in Schussler et al’s (2008) study demonstrate the

potential flexibility and fluidity of this commitment. Willingness to consider alternative pedagogical approaches to the ones they experienced as students is a resource that our responsive teaching professional development could tap into to help encourage TAs to adopt more responsive instructional approaches and strategies that focus more primarily on student ideas and thinking.

Disciplinary expertise is another resource that TAs have that could be a foothold for developing responsive teaching strategies (Ball et al., 2009; Ball, Thames & Phelps, 2008). This resource can be leveraged in two ways: 1) TAs' content-mastery of the topics they are teaching can allow them to focus more on pedagogical approach than on understanding content and 2) TAs' experience with making sense of ideas they hear from colleagues and advisors as part of their research experience can be applied to articulations from their students.

The TAs in our study had a level of expertise in biology that stemmed from recently completed (and oftentimes, currently ongoing) coursework and research experience. Therefore, energy and time that might have been spent on clarifying and understanding the content that they are teaching could instead be focused on developing a pedagogical approach that centralized student ideas (Ball, Thames & Phelps, 2008; Thames & Ball, 2010). To be clear, while disciplinary expertise can be an affordance for responsive teaching, it can also be a barrier if coupled with a strict interpretation of the canon (as with Julian). Since our TAs already possessed the content mastery, we intended to leverage our professional development to help TAs focus on encouraging and developing responsive teaching abilities.

Furthermore, because of their involvement in research, TAs regularly engage in making sense of ideas that their peers, colleagues and advisors bring up. While TAs might view the ideas of fellow researchers as having more value than the ideas of inexperienced undergraduate

students, the practice at making sense of those ideas is a resource we hoped to leverage in our professional development.

There is evidence that novice teachers are capable of noticing student thinking, specifically in science. Novice teachers such as TAs have shown the ability to notice student thinking both in written work (Hill, Gouvea & Hammer, 2018) and in class discussions (Grinath & Southerland, 2019). While there is evidence that this noticing ability is episodic in novice teachers rather than consistent (see Levin & Richards, 2010), the kernels of ability shown in these other studies is something that we hoped to build on by specifically focusing TAs pedagogical awareness on responsive practices.

Our goal with the professional development was to give our TAs a low-stakes, group-oriented environment in which to practice responsive teaching techniques. We wanted to give TAs opportunities to learn to overcome the challenges of responsive teaching, notably intentionally noticing the presence of student ideas, attending to the substance and potential merit of student thinking and determining how to respond to those ideas, even when they were not aligned with traditionally accepted disciplinary knowledge. We wanted to build on resources that TAs already had – willingness to consider new pedagogical approaches, disciplinary content-mastery and research-based practice at making sense of ideas – to help them engage with responsive teaching as a pedagogical approach with value. To create the professional development, we turned to the literature on teacher training to try to identify what sort of activities to design into our PD meetings that would build on the resources the TAs possessed to address the challenges associated with responsive teaching.

VI. Professional Development

We designed a professional development for biology TAs that was grounded in an emphasis on responsive teaching. As noted, instructors may find noticing and attending to student thinking challenging; and the work of responding to the disciplinary substance of students' ideas takes practice and intentionality (Ball, 1993; Coffey, Levin, Hammer & Grant, 2011; Hammer, 1997; Hammer, Goldberg & Fargason, 2012; Rosenberg, Hammer & Phelan, 2006). We turned to the existing body of research on responsive teaching professional development in math and science with these challenges and novelties in mind when we designed our PD. Through a review of this literature, we decided to structure the PD around a commonly used tool: classroom video.

Observing and discussing video data of live classroom instruction can be a powerful training tool for developing teaching practices (Sherin & van Es, 2005), particularly as a way to provide teachers with practice noticing and engaging with student thinking and ideas (Levin & Richards, 2011). Classroom video is a tool that we used in two ways in our professional development:

1. Observing video of students talking and engaging in lab activities to practice shifting attention to *noticing student ideas* and to start encouraging a shift towards focusing *attention on the substance and merit of student thinking* over strict canonical correctness.
2. Observing video of teachers making moves in response to student ideas to begin to develop *methods of responding* in the moment that encourage thoughtful disciplinary engagement while avoiding confusion over nonstandard knowledge.

Watching classroom video of students engaged in discussion and activity can be a lowstakes way for teachers to get practice at listening for ideas (Levin & Richards, 2011; Roth et al., 2011; Sherin & van Es, 2005). Because it can be difficult to focus on student thinking while

simultaneous classroom pressures are occurring (see Schoenfeld, 2011; Richards et al, 2020), watching video of students engaging in scientific discussion and practice can give teachers an opportunity to focus on what the students are doing in the absence of those distractions. The challenge of simply noticing that a student is articulating an idea can be alleviated by watching video of students articulating ideas and having the stated reason for watching the video be noticing and commenting on those ideas. Furthermore, practicing identifying student thinking that is present in recorded video has been shown to help develop that ability in novice teachers for use in actual live classroom settings (e.g., Levin & Richards, 2011, van Es & Sherin, 2010).

Van es and Sherin (2010) conducted an analysis of a video-based professional development program in which middle school mathematics teachers participated in ‘video clubs.’ During monthly club meetings, participants in the professional development would watch video clips from each other’s classrooms and discuss moments of student-student interactions (van Es & Sherin, 2010). The researchers found that over the course of the year, teachers’ ‘professional vision’ improved in the sense that they became more skilled at noticing and interpreting moments from these videos in which students were sharing mathematical ideas (van Es & Sherin, 2010). Most interestingly, the teachers showed evidence of improved noticing abilities both within the context of video club meetings as well as in interviews with researchers and during live instruction in their own classrooms (van Es & Sherin, 2010). That is, by practicing noticing student engagement in a PD environment that intentionally limits distractions, novice teachers became better at noticing even in the distraction-laden environment of a live classroom.

A part of watching classroom video clips is the ensuing discussion among PD participants about what they noticed and attended to. We anticipated that TAs give more attention to factually incorrect aspects of student ideas (as suggested by Goertzen, Scherr & Elby, 2010, and

in prior work by Hill, Gouvea & Hammer, 2018). The key to driving a shift away from this epistemology about teaching and towards one that elevates and interrogates student ideas for substance is in the transparency of our goals of the training. We made clear to the TAs in our PD that what we were asking them to do – attend to the substance of the student ideas even if they are “wrong” – is hard! We wanted our TAs to feel comfortable discussing this challenge and creating a community feeling that allowed them to support each other in changing their perspectives.

The other primary element of our video-club responsive teaching PD for TAs was an assigned reflective teaching journal (RTJ) that the TAs added to weekly. For the assignment, TAs were asked to reflect each week after their teaching labs on a moment from the lab that interested them.

Our inspiration for inclusion of the RTJs was grounded in existing literature that highlights their use in other PD settings. For instance, Schussler et al (2008) used reflective teaching journals in a professional development for biology TAs as a tool for guiding TAs through pedagogical transformation. Specifically, the authors report that giving TAs opportunities to observe and reflect on teaching practices in writing led to the shaping and formalization of a teaching philosophy. Schussler et al (2008) also noted that the written reflective practice enabled the TAs to question traditional teaching practices and recognize the challenges of implementing a new pedagogical approach. A more comprehensive literature review of the historical use of reflective teaching journals can be found in Study One below. Here we simply note that the literature on RTJs typically focuses on their utility as a way for teachers to reflect on teaching practice. Our usage of the RTJs was directed towards developing the TAs’ noticing abilities and engagement with student thinking and ideas.

VII. Professional Development to Leverage Resources and Address Challenges

Responsively taught classrooms have documented benefits for students (see Robertson, Scherr & Hammer, 2015 for a review). When student ideas are elicited, noticed, attended to and responded to in ways that elevate their importance and consider their merit:

- *Students feel more confident sharing their ideas and more equitable participation occurs.*
- *Students feel more comfortable articulating their thinking and thus feel more agential in their own learning.*
- *Students are more willing to interrogate the ideas of their peers and disciplinary engagement and argumentation often ensue.*

In light of our goals for our introductory biology lab curriculum – to get students doing science – we believed that the benefits afforded by responsive teaching made it a sound instructional approach for our TAs to implement in their teaching labs. The actions that responsive teachers are responsible for engaging in – drawing out, noticing, attending to and responding to student ideas – can prove challenging for teachers of all experience levels. Given the lack of pedagogical experience that our TAs had as instructors of the labs, we identified specific challenges they might face when asked to teach the labs responsively:

- *Overcoming distractions in the classroom to notice the presence of student ideas.*
- *Shifting their beliefs about their roles as teachers away from directing students towards the correct answers and towards attending to the substance and potential merit of student-generated ideas.*

- *Developing methods of responding to student ideas that encouraged them to build on their thinking and hold agency over their ideas*
- *Feeling confident about responding to complex or unclear student ideas in ways that avoid propagating factually incorrect disciplinary content*

Our goal for our responsive teaching-based professional development was to address these challenges by drawing on the literature and on resources that TAs already possess, including their willingness to consider novel instructional methods, their disciplinary contentmastery and their experience with making sense of novel disciplinary ideas.

When unexpected student-generated ideas (like Nick's silent mutations) inevitably emerged because of the lab curriculum, we wanted our TAs to notice and engage with the substance and potential merit of those ideas. This style of teaching may be in opposition to what some TAs initial inclination might be, such as Julian's practice of focusing on the degree to which student articulations matched instructionally expected answers (Goertzen, Scherr & Elby, 2010). Guiding the TAs towards a more responsive approach to these moments was the goal of our professional development. By teaching the TAs how to create a classroom culture that elevated the importance and merit of student thinking and ideas, the benefits of responsive teaching could emerge in the form of rich discussion and interrogation of ideas like what was observed in Deborah Ball's math class (1993).

Through a review of the literature, we believed that using classroom video in the style of Van Es & Sherin (2010) along with reflective teaching journals as tools for giving TAs lowstakes, collective practice at noticing and attending to student thinking would be productive and generative in our professional development. We intended to give the TAs space to discuss the challenges they had with shifting their perspectives on teaching towards responsiveness with

a problems of practice attitude as in Garrison and Kanuka's (2004) work. We believed that this would help to create the PD environment we were seeking in which TAs were comfortable talking about their personal beliefs and challenges associated with teaching.

By being transparent in the purpose of the discussions we engaged in in the PD, and by purposefully drawing on the TAs existing resources including their expert-level content mastery and experience with making sense of topical ideas, we believed we could develop the TAs' sense of why it is a good thing to attend to student thinking rather than simply student correctness. We believed that the discussions we had after watching classroom video would provide evidence to the TAs that they can respond to student ideas in ways that further their disciplinary understanding without supporting "wrong" or flawed ways of thinking about biological concepts.

Finally, we expected to continually need to shift and adjust our approach as developers and leaders of the PD to meet the needs and expectations of the TAs – that is, we expected to need to be responsive! The guided reflective discussions that occurred in the PD, by nature, shifted and changed in real-time depending on the current issues that TAs were feeling challenged by. The overarching goals of the activities and episodes we used in the PD were to help our TAs begin to focus on and emphasize the scientific substance and merit present in student thinking and respond to that thinking in ways that drove thoughtful, collective discussion of disciplinary ideas; the methods by which we attempted to achieve these goals were necessarily changeable depending on moment to moment context.

VIII. Research Questions

The focus of this dissertation research is on investigating the ways biology TAs experienced, engaged with and were impacted by a responsive teaching professional

development. Below we report on three analyses that we conducted on the data we collected during the PD semester. While each study will support and address its own specific research questions, the overarching goals of this dissertation work are to address the following broad questions:

- *What evidence did TAs show of noticing and responding to student thinking as the semester of PD progressed?*
- *What design elements of the PD supported TAs in developing their abilities at noticing and engaging with student thinking and ideas?*
- *How did the PD influence the ways in which TAs considered and reasoned about student ideas?*
- *Did the ways in which TAs developed their noticing and responding skills in the PD translate to implementation of responsive practices in their teaching labs?*
- *How could future responsive teaching-focused PD be designed to more effectively encourage responsive practices from TAs?*

At the conclusion of our reporting on these three studies, we will derive some implications and make some suggestions for how professional development can be used in the future to help encourage and support teachers in listening for, attending to and engaging with the disciplinary substance and merit of student thinking and ideas.

Research Context and Methodology

Here we provide the general context and methodology for the entirety of the research that is the substance of this dissertation. Reiteration of relevant study-specific methods as well as the particular analytical approaches used in each study will be provided in separate methods sections for Studies One, Two and Three respectively below.

I. Study Context

We constructed our professional development to be a space within which biology graduate student TAs could be exposed to and get practiced at responsive teaching. Concurrently with the PD, the TAs were teaching an inquiry-based introductory biology laboratory for college undergraduate students.

The TAs who participated in our PD were concurrently teaching sections of an introductory biology lab called BIO14: Organisms and Population Biology. The BIO14 lab curriculum consisted of three model study systems: *Escherichia Coli*, *Mimosa pudica* (sensitive plant), and *Callosobruchus maculatus* (bean beetle). Each model study system was investigated over a three-week period in which the students designed and conducted experiments about the organism, worked with a computer simulation about the organism and then synthesized and analyzed results from the experiments and simulations. Each study system was oriented around an ecological trade-off question:

1. *E. coli*: Is it better to mutate a lot or a little?
2. *M. pudica*: Is it better to forage (photosynthesize) or hide (fold up leaves)?
3. *C. maculatus*: Is it better to lay a lot of eggs indiscriminately, or fewer eggs more choosily?

As part of their position, the TAs were required to attend a weekly prep session before teaching their lab sections. The prep sessions were intended to give the TAs the chance to troubleshoot lab protocols and get a sense for what kinds of student ideas might come up. While pedagogy was not a sole focus of these prep sessions, teaching strategy was often discussed as a broader part of executing specific parts of the weekly labs. For instance, when walking through the protocol for an experiment investigating *E. coli* mutation rates, part of the discussion in prep became about how best to encourage student-student discourse during experimental design discussions.

Prior to the weekly prep sessions, TAs attended a one-time pre-semester workshop aimed introducing TAs to the pedagogical approach to teaching the labs. In this workshop, we gave the TAs examples of student ideas that emerged during previous years of the lab both in class discussions (in the form of video clips) and in written student work. The goal was to begin to frame the role of the TA as attending to students' ideas and to expose TAs to examples of student thinking they might encounter in the labs.

Finally, the PD course we designed was offered as an option to all TAs and undergraduate LAs. The course met for 75 minutes once per week for nine weeks (the same amount of weeks as the BIO14 lab ran). Nine students enrolled, five of whom were graduate TAs. The course was structured around giving the participants practice at noticing and engaging

with student thinking and ideas through written assignments and in-person conversation about moments of student thinking from their teaching labs.

II. Participants

This dissertation is focused on the experiences of the five graduate student teaching assistants who participated in the responsive teaching PD. All five participants were biological science graduate students (two were Ph.D. candidates, three were M.S. candidates) at a medium-sized private university in the Northeast whose teaching assistantships were awarded as part of their acceptance to the graduate school. The TAs will be referred to throughout this work as:

Susan, Ella, Charlie, Jake and Sadie (all pseudonyms).

III. Data Collection

We collected four main kinds of data: TA reflective teaching journals, TA interviews, professional development class video data, and BIO14 lab video data. TAs involved in the professional development gave informed consent to participate in the study and to allow data collection, analysis and presentation that included their participation in the course (IRB #1904014).

a. TA Reflective Teaching Journals

As a part of the PD, we assigned the TAs with keeping weekly reflective teaching journals in which they were instructed to write about a moment from their teaching that stood out to them. Specifically, we asked our TAs to reflect on their teaching experience each week and “describe a moment from your lab that was interesting to you. This moment should be about something that involved your students.” Each week, the TAs submitted a journal entry on a

password protected drive that was accessible by only the TA and the course instructors. One instructor provided written electronic feedback on each entry.

b. TA Interviews

Each of the five TAs who participated in the professional development also consented to be interviewed at the beginning (within the first 14 days) and end (within 14 days from the final day) of the semester. The interviews were semi-structured around two main questions:

1. What has stood out to you from the PD?
2. What has stood out to you from BIO14?

In each interview, we asked the TAs to do their best to recount some specific moments from both the PD class and their teaching labs that stood out to them. Following their description of the moments, we engaged in discussions about why those moments stood out and how the TAs interpreted them. The semi-structured nature of these interviews also allowed for conversation about other things that came up organically during the interview (e.g., in the preinterviews, TAs often talked about why they decided to take the PD course).

c. Video of the Professional Development Class

The weekly 75-minute professional development class sessions were video recorded with the consent of the participant TAs and instructors. All video files were immediately downloaded from the recording devices and stored on a password protected hard drive for future transcription and analysis. Given the relatively small group size and conference table set-up in the room, a single video recorder (with audio recording capabilities) was all that was required to record these sessions.

d. Video Data from TA Lab Sections

As part of a simultaneous research project that focused on student learning and engagement, several sections of the BIO14 lab were being video recorded during our semester of professional development (IRB #1412014). Two of the TAs that participated in our PD had previously consented to having their BIO14 lab sections recorded as part of this student-focused research. The students for those sections also consented to being recorded for research and publication purposes.

In addition to the cameras in the labs as part of this research, we also (with consent) placed audio recorders with lapel microphone devices on the two TAs themselves so that we could record their small-group interactions with students. All the video and audio recording files were immediately downloaded from the devices and stored on a password protected hard drive for future transcription and analysis.

IV. Analyses

Details of the analytical methods used in this research will be explicated on below in ways that are specific to each of the three studies being presented. Our overall analytical approach was centered on examining how the TAs engaged with student thinking through their written journals, in-class teaching and dialogue during the PD. As such, we chose to largely be episodic in our analysis so that we could more deeply examine the substance of the moments in which TAs engaged with student thinking.

What follows are descriptions of three analytical studies born of the data collected as described above. The studies are intended to collectively address the research questions identified above. As each study is meant to focus on specific results and outcomes of our responsive teaching professional development for graduate student teaching assistants, each is

written complete with individualized introduction, methods, results and discussion sections as would be seen in published research articles.

Study One – Responsive Teaching Professional Development: Using Teaching Journals to Examine Graduate Student Teaching Assistants’ Interactions with Student Thinking I. Introduction

a. Responsive Teaching is an Approach to Instruction that Benefits Students

Responsive teaching is an instructional approach that encourages teachers to notice and respond to the disciplinary substance of student thinking and ideas (Robertson, Scherr & Hammer, 2015). A goal of responsive teaching is to increase the frequency and consistency with which teachers focus their attention on student thinking and ideas. For example, Maskiewicz & Winters (2012) documented a fifth-grade science teacher, Mrs. Charles, who demonstrated adeptness at noticing student thinking. Early on in her class, Mrs. Charles posed a question to her students about why puddles of rainwater visible in the parking lot when students arrive to school would disappear by the time the students leave for the day. Mrs. Charles notes that during the ensuing discussion, “[The teacher is] constantly on [his or her] toes, evaluating, listening, and thinking” (Maskiewicz & Winters, 2012, p. 452). As a result of this attitude, Mrs. Charles was able to notice her students have ideas about a wide variety of potential explanations for the phenomenon including shade, temperature and evaporation (Maskiewicz & Winters, 2012). The concepts of surface area, dryness, fog and condensation also emerged from students and were picked up on by Mrs. Charles (Maskiewicz & Winters, 2012). Her ability to notice and respond to the ideas put forth by her students allowed Mrs. Charles to foster a classroom environment that encouraged her students to engage in deep conceptual thinking and to feel comfortable sharing their ideas with the class (Maskiewicz & Winters, 2012).

More generally, there is evidence that when students feel like their thinking and ideas are part of the substance of what goes on in the classroom, they more deeply engage with conceptual content (Ball, 1993; Warren et al, 2001; Hammer, Goldberg & Fargason, 2012). Eliciting and interpreting student thinking can also inform instruction that allows teachers to better engage with and build on student ideas (Maskiewicz & Winters, 2012). That is, when it becomes commonplace that student ideas are foregrounded in a class, teachers are afforded more opportunities to engage with those ideas as part of the substance of teaching and learning.

b. Graduate Student Teaching Assistants Generally Lack in Pedagogical Experience and Training

Most of the research on responsive teaching has been implemented in K-12 education. This research suggests that for K-12 teachers, attention towards student thinking is both episodic (Levin & Richards, 2011; Sherin & Russ, 2014) and context-dependent (Levin, Hammer & Coffey, 2009; Sherin & Russ, 2014; Barnhart & van Es, 2015; Richards et al, 2020). Given that many K-12 teachers are focused on delivering content, they often tend to pay minimal attention to students' ideas (Richards et al, 2020). Training teachers to focus on their students' thinking rather than just on conveying their topical expertise is a challenge facing education practitioners (Goertzen, Scherr & Elby, 2010; Richards et al, 2020).

Less research has examined responsive teaching in the context of higher education. In this work we focus on graduate student teaching assistants (TAs). TAs are a population of novice teachers who are in the process of developing disciplinary expertise in their field but who generally lack pedagogical experience and training (Schussler et al, 2015). In biological science programs at the university level, TAs are often awarded teaching assistantships for which they receive financial support in exchange for teaching an undergraduate-level biology laboratory

course. Despite their typical status as novice (or even novel) teachers, there is little in the way of pedagogical training or support made available for TAs (Schussler et al, 2015).

TAs are an important population of teachers at the college level, especially in the sciences. Many introductory-level science courses have laboratory and discussion sections that are taught by TAs – that is, many undergraduate students’ first exposure to college-level science is with a TA as an instructor. Because of the demands of graduate level science programs, TAs may not have a specific interest or desire to teach or think critically about pedagogy – their focus may tend to be more on their own personal research that furthers their progress towards a graduate degree. Yet there have been successful reports of encouraging responsive teaching in graduate students (Gehertz, Brantner & Andrews, 2022; Grinath & Southerland, 2019). Graduate student TAs have shown the ability to redirect focus away from superficial indications of student correctness and towards the substance of student ideas (Goertzen, Scherr & Elby, 2010). Furthermore, there is evidence to suggest that when TAs enact more responsive discourse moves, the quality of student discourse in the classroom improves (Grinath & Southerland, 2019).

To build on this emerging work, we designed a professional development that encouraged TAs to take a more responsive approach to teaching. As a part of this PD, we used teaching journals as a tool to give the TAs an opportunity to catalog and reflect on moments from their teaching with a specific focus on their students.

In the next section, we briefly review the uses of journaling in teacher professional development more broadly, and then discuss how we used journals to support responsive teaching specifically. We explain how the TA journals helped us see evidence of noticing, interpreting and responding patterns that the TAs engaged in during their teaching. Finally, we discuss what these findings suggest about the ways the TAs may have been impacted by our PD.

c. Reflective Teaching Journals as Tools for Practical Reflection

The main use for reflective teaching journals (RTJs) in past work has been as a tool for teachers to reflect on their own practice. That is, RTJs have been used in education research to give after-the-fact space for instructors to think about what happened during their live teaching. Researchers have then studied these journals to gain insights into the nature of instructors' reflections. For example, Isikoglu (2007) used RTJs to try to better understand how pre-service early childhood education teachers reflected on their teaching. Some teachers engaged in "critical" reflections, characterized as being focused on analyzing their educational practices and considering the implications of those practices on the classroom (Isikoglu, 2007). Other teachers engaged in "routine" reflections, described as descriptions of teaching moves in terms of their success or failure (Isikoglu, 2007). The researchers used the analyses of the journals to highlight differences in how teachers were thinking about pedagogy.

Similarly, Gallego (2014) analyzed 177 reflective teaching journal entries from graduate student teaching assistants (TAs) in a university humanities program and found that the most prevalent topics written about by TAs were 'methodology' and 'classroom management.' Journal content coded as 'methodology' was grounded in TAs writing about specific teaching moves that they thought about or tried (Gallego 2014). The 'classroom management' category included entries in which TAs wrote about ways to maintain behavioral discipline or encourage specific kinds of activities in the classroom (Gallego 2014). In these studies, journals were primarily used to give researchers insight into the nature and substance of teacher reflections.

Researchers have also used journals to investigate instructors' openness and willingness to consider alternative pedagogical approaches. Schussler et al (2008) report that the written reflective practice of RTJs enabled the TAs in their study to question traditional teaching

practices and recognize the challenges of implementing a new pedagogical approach. Isikoglu's (2007) work showed teachers who engaged in "critical" reflections were more likely to exhibit willingness to alter their approach, while the teachers who engaged in "routine" reflections, were less likely to engage in professional development and change.

d. Our Use of Teaching Journals as a Tool for Practicing Noticing Student Thinking

Because evidence from these prior studies suggests RTJs can be a useful tool for teachers to reflect on practice – and a useful data source for researchers to better characterize and understand those reflections and practices – we decided to investigate whether journals can be used to help teachers focus on *student thinking*.

We wanted to incorporate a teaching journal assignment into our PD that would give the TAs an opportunity to note and engage with specific moments of student thinking that happened in the classroom. Rather than asking the TAs to specifically reflect on pedagogy or even on practice more generally, we wanted the journals to function as a space for our TAs to practice noticing moments of student thinking. We then analyzed the TAs' journal entries to understand the role the journals may have played in helping to motivate them to focus on student ideas as part of a more responsive approach to instruction. Our analysis of the TAs' journals was aimed at addressing three questions:

- How frequently did the TAs notice and write about student thinking and ideas in their journals?
- How did the TAs interpret student thinking and ideas in their journals?
- How did the TAs report on responding to student thinking and ideas in their journals?

Our analysis of the TAs' journals will include an examination of the ways in which TAs interpreted and responded to the substance of the ideas and thinking that they noticed students articulating. We will draw connections between these patterns and the TAs' involvement and engagement with our responsive teaching PD.

II. Methods

a. Study Context

The TAs who participated in our PD were concurrently teaching sections of an inquirybased introductory biology lab called BIO14: Organisms and Population Biology. The BIO14 lab curriculum consisted of three modules that each focused on a particular model study system:

Escherichia Coli, *Mimosa pudica* (sensitive plant), and *Callosobruchus maculatus* (bean beetle).

Each model study system was investigated over a three-week period in which the students designed and conducted experiments about the organism, worked with a computer simulation about the organism and then synthesized and analyzed results from the experiments and simulations. Each study system was oriented around an ecological trade-off question:

- *E. coli*: Is it better to mutate a lot or a little?
- *M. pudica*: Is it better to forage (photosynthesize) or hide (fold up leaves)?
- *C. maculatus*: Is it better to lay a lot of eggs indiscriminately, or fewer eggs more choosily?

Teaching this style of inquiry-based lab inevitably (and intentionally) led to moments in which the TAs encountered student ideas and questions that they had not previously anticipated or prepared for. These kinds of incidents left the TAs in position to make in-the-moment

decisions about how to respond, decisions that were undoubtedly influenced by the substance of what they noticed in student articulations.

As part of their position, the TAs attended a weekly prep session before teaching their lab sections. The prep sessions were intended to give the TAs the chance to troubleshoot lab protocols and get a sense for what kinds of student ideas might arise. While pedagogy was not a sole focus of these prep sessions, teaching strategy was often discussed as a broader part of executing specific parts of the weekly labs. For instance, when walking through the protocol for an experiment investigating *E. coli* mutation rates, part of the discussion in prep became about how best to encourage student-student discourse during experimental design discussions.

Prior to the weekly prep sessions, TAs attended a one-time pre-semester workshop aimed at introducing TAs to the pedagogical approach to teaching the labs. In this workshop, we gave the TAs examples of student ideas that emerged during previous years of the lab both in class discussions (in the form of video clips) and in written student work. The goal was to begin to frame the role of the TA as attending to students' ideas and to expose TAs to examples of student thinking they might encounter in the labs.

b. Responsive Teaching Professional Development

The PD course met once per week for 75 minutes on Monday mornings, prior to the weekly BIO14 lab section schedule. Given that the lab prep sessions were on Fridays (after the conclusion of the last lab of the previous week), the TAs in our PD always had both prep and PD prior to their teaching assignment each week.

We constructed our professional development to be a space within which biology graduate student TAs could be exposed to and get practice at responsive teaching. One central component of the seminar was a video club in which TAs shared and discussed video clips from

their lab sections. Math education reform has found success with the use of video clubs (Sherin & van Es, 2005), in that having teachers watch video of classroom instructional moments helped them gain experience and practice at noticing student ideas and thinking. We wanted to implement a similar strategy in our PD for biology TAs. Specifically, we wanted our PD to revolve around watching and discussing video from the TAs' labs to get low-stakes practice at noticing and responding to student ideas and thinking as well as to consider multiple possible ways of responding.

We assigned each TA two dates during the semester to bring in a short (3-5 minute) video clip from their lab. We instructed the TAs to bring in clips of moments that they found “interesting” or that “stood out” to them. Our PD sessions were then mostly taken up by viewing and discussing these video clips. The pressures of a classroom (i.e., time management, personal interactions with students) are not present in a PD class and this seemed to give our TAs room to feel comfortable sharing their struggles and also collectively working together to improve practice. Given the novice status that our TAs shared, we found it effective to provide space for them to work together to understand student thinking to the point that we could begin to craft potential responses to student-raised ideas and questions. This ‘problems of practice’ approach has been used previously to help facilitate instructor support by giving teachers shared space to discuss and work through challenges as a group (Scardamalia, 2000).

We (the PD instructors) tried to direct the flow of the video-based discussions towards two main goals: 1) identifying and making sense of student ideas and 2) developing a suite of potential ways to respond to those ideas. During the first half of the semester, we focused primarily on the former and we introduced the later during the second half of the semester. Early on during the PD, it took focused effort to direct the TAs away from discussing the details of the

science and towards noticing and making sense of what students were doing and saying. For instance, in the third PD session, the TAs watched a video clip of students trying to make sense of the results of an experiment in which *E. coli* bacteria were grown in different environments. During the ensuing discussion about this clip, the TAs became enamored with trying to explain the results of the experiment themselves, rather than trying to understand the ideas that the students were coming up with in the video clip.

Later in the semester, the TAs watched a video clip of students proposing mechanisms that might explain the egg-laying behavior of female bean beetles. The students were trying to come up with explanations that would account for egg-laying data that was given to them. This was another opportunity for the TAs to engage in intense discussions about the science, to try to make sense of the data set and propose their own explanations for the trends. However, in this instance, seven weeks into the PD course, the TAs instead engaged in a discussion of rearticulating the ideas that the students had come up with in the clip. Rather than apply their own scientific thinking, they efforted at making sense of student ideas.

Another part of the PD involved keeping weekly teaching journals in which TAs were instructed to write about a moment from their teaching that stood out to them. Specifically, we asked our TAs to reflect on their teaching experience each week and “describe a moment from your lab that was interesting to you. This moment should be about something that involved your students.” We loosely structured our journal assignment around the same substance that the entire PD was structured around: student thinking. Using the journals to potentially give practice to the TAs at noticing and attending to moments of student thinking in their classrooms allowed us to then use the in-class meetings of the PD to practice *responding* to those ideas in a lowstakes environment surrounded by peers. The substance of these teaching journals will be the analytical focus of this paper.

c. Study Participants

Five graduate student teaching assistants and four undergraduate learning assistants participated in our responsive teaching PD though we only focus on the graduate students for this study. All five graduate students were enrolled in degree programs in the Biology Department (two were Ph.D. candidates, three were M.S. candidates) at a medium-sized private university in the Northeast whose teaching assistantships were awarded as part of their acceptance to the graduate school. The TAs will be referred to in this paper as: Susan, Ella, Charlie, Jake and Sadie (all pseudonyms).

d. Data Collection

Journal entries were collected each week for nine weeks of the semester yielding a total of 38 entries across the five TAs (7 potential entries were not submitted). TAs were instructed to write their journal entries after their teaching lab period and submit them before the next meeting of the PD course. While we suggested that journals be written up soon after lab sessions to help preserve memories of moments, most entries were submitted the night before or morning of the next PD session. All journal entries were submitted to and stored on a password-protected drive and were only accessible by the TA who wrote the entry and the PD instructors.

One instructor left written feedback on the journal entries each week in the form of electronic comments that were immediately visible to the TAs. This feedback was not evaluative in nature but was often written in the form of questions, asking for clarification or elaboration on what the TAs wrote. Despite the invitation for conversation that this feedback provided, TAs did not engage in written back and forth.

e. Analytical Process

i. Phase One: Identifying Moments

The first phase of our analysis began with the process of reading through the journal entries and identifying the specific moments of instruction that the TAs were writing about. Our requirement for a journal excerpt to be considered a ‘moment’ was the inclusion of enough written description that the excerpt would be recognizable in hypothetical video recordings of the lab. That is, a journal episode catalogued as a ‘moment’ had to be described with details that separated it from general commentary. An example that did *not* count as a moment came from Ella’ week 2 journal:

This week was a lesson/reminder in group/time management. I forgot how challenging it can be to manage 9 groups as they are thinking through their experimental design while avoiding any one group monopolizing your time.

Here, Ella is commenting on general challenges she experienced in her lab with time management and group differences. This comment is not specific enough to anything that happened during Ella’s week 2 lab that we would be able to identify it as a distinct moment if we were either present for the lab or had video recorded it. In contrast, in week 4, Susan wrote:

I feel like the inconsistency between me and [my learning assistant] is getting stronger. We might talk to the same group but say different things. For example, I told students to do six trials if they had enough time, while she said they only needed to do four.

In this excerpt, Susan provides much more detail about the specifics of the moment. Had we been observing Susan’s lab, we would have been able to identify this moment when she and her learning assistant gave conflicting advice to the same group of students. In total across the five TAs, we identified 100 descriptions of specific moments.

ii. Phase Two: Identifying Moments about Student Thinking

In the second phase of analysis, we examined these 100 moments to determine what the TA was noticing in each. Specifically, we attended to the frequency with which TAs noticed student thinking and ideas. For the moment to be considered evidence of a TA noticing ‘student

thinking,' the journal entry must have included details about an idea articulated by a student (or students) that was grounded in disciplinary substance. That is, an entry that included language like: "Many students designed experiments about competition" (Charlie, Week 2) was not considered indicative of noticing student thinking. These general statements about lab-wide trends were more reflective of the TA noticing procedural patterns in the lab than specific ideas that students had. In contrast, student-thinking-centered journal entries included specific explanations of disciplinary, biology-based ideas and thoughts that students had (bolded text in the example below is the student idea):

In tonight's class, one [of] my quieter students sort of took to the simulation to explore some of his ideas. We actually got him a second computer because he wanted to keep one simulation running while setting up another. **He was exploring the influence that lethal mutations has on the outcome of the competition. In other words, he wanted to explore whether there was a threshold at which point the high mutator would have the advantage, or if getting any amount of lethal mutations would always favor the low mutator.** (Ella, Week 3)

In this example, Ella chose to write about a moment (one that would clearly be definable in classroom video) in which she noticed disciplinary thinking that was generated by a student. The idea at hand appears to be about an investigation that a student wanted to undertake ("...he wanted to explore whether there was a threshold at which point high mutator would have the advantage...").

In week 5, Charlie wrote the following about ideas that his students had relating to the sensitive plant lab:

Their hypothesis was that cut plants will open faster since they need to now gather more energy to make up for the missing leaf. Their experiment showed that the cut plants opened slower. When I asked them why, they thought for a bit and **came up with the idea that the plant opened slower to protect itself in case the threat was still there.**

Here, Charlie is identifying a biological hypothesis that his students generated about the plants and then (after some follow up), a proposed explanation for that hypothesis that was grounded in disciplinary substance (“...the plant opened slower to protect itself...”). This notion of protection was part of the biological trade-off (protection versus photosynthesis) that was discussed at the beginning of this lab. As with Ella’s example above, this example illustrates what we coded as a TA noticing a ‘moment of student thinking.’ The description of the moment includes fine-grained details about biology-based thinking and articulating on the part of the student(s).

iii. *Phase Three: Characterizing how TAs Interpreted Moments of Student Thinking*

In the third phase of analysis, we turned our focus to how the TAs *interpreted* the moments they identified. Broadly, TAs tended to interpret student ideas either positively or negatively. For instance, in week 2, Sadie writes about the idea that a group of students had for a bacteria experiment:

One group suggested using a mutagen by putting their cells under a UV light. No one else, to my knowledge, has tried using a UV light. We ended up using the GelDoc, as it was the safest way to expose bacterial cells but not human cells to the UV light. We had discussed mutagens in a previous class discussion, so *I was excited to see them applying the discussion topics to their actual experiments.*

The italicized text here is to note Sadie’s positive interpretation of the thinking put forth by her students. We often saw words like “excited,” “awesome,” “encouraged,” “pleased,” and “impressed” when TAs interpreted student thinking positively. These comments framed students’ ideas or actions as assets to be valued.

Other times, TAs interpreted student thinking with a more negative tone. These comments framed students’ ideas or actions in a more deficit-based way. For example, in week

5, Jake writes about a student trying to explain an idea about how sensitive plants developed their traits:

As one student mentioned, “plants probably evolve this flexible behavior to live in all sorts of climate and regions, which allows them to have a high survival rate.” This statement was interesting because most students know that Mimosa plants can live in a wide range regionally and can survive in a lot of different climates. However, what they don’t understand was why plants would evolve such a behavior in the context of physiology and having an evolutionary advantage. *There was a clear gap in knowledge and many students had trouble linking the physiology component—the need for sunlight as a resource—to the evolutionary mechanism.*

In this instance, Jake interprets the student idea in a more judgmental way as evidence that the students were misunderstanding or lacking in their content knowledge. Phrases like, “missing something,” “they didn’t get it,” “confused,” and “discouraged” were more common in the TAs’ negative interpretation. In these comments, TAs framed students ideas or actions in deficit terms, emphasizing what they lacked or had wrong.

We further analyzed the ways the TAs interpreted student thinking and ultimately found three consistent categories of interpretation. TAs consistently interpreted student ideas as being: *positive, confusing or incorrect.* Table 1 below explicates on these categories with examples.

Table 1. Three types of interpretations TAs frequently had about moments of student thinking. Bold text denotes the student thinking being noticed; italics denotes the coded interpretation.

Interpretation of Student Idea	Description	Example
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Positive	When TAs interpret student ideas positively, they often exhibit feelings of being impressed by, pleased with or appreciative of student contributions.	<p>Another group wanted to test untransformed bacteria to see if they could mutate ampicillin resistance on their own. They had transformed bacteria as controls and plated untransformed bacteria on amp plates. I liked this experiment because I had essentially told everyone that all transformed cells were amp-resistant, and the untransformed cells were essentially for use on the McConkey plates. <i>I appreciated their out-of-the-box thinking in wondering, “given that spontaneous rif-resistance can occur, can amp-resistance do the same thing?”</i></p>
Confusing	When TAs interpret student ideas as being confusing, they often exhibit evidence of being thrown off by student ideas that they consider to be weird/bad/unclear.	<p>After giving them some time to discuss the model in their small groups, I asked 1 group to share their whiteboard. I knew that they had tried to represent the model graphically, but I didn't know the specifics of their ideas so I thought it might be an interesting starting point. Below is their idea, but after a few rounds of edits. They initially had resource quality on the y-axis and number of eggs that would be laid on the x-axis. <i>So obviously this was pretty confusing and not what I was expecting.</i></p>

Incorrect	When TAs interpret student ideas as being incorrect, they often exhibit criticism, judgement or dismissiveness about ideas that students have.	<i>Though I think he knew better (and ultimately corrected himself) he started out by saying that in the absence of competition, deleterious mutations would have no effect. I think he meant that given unlimited resources (no competition) mutations that did not confer a metabolic advantage would not inherently mean that the cells are at a disadvantage.</i>
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iv. Phase Four: Characterizing how TAs Reported Responding to Student Thinking

In the fourth phase of analysis, we examined journal entries for evidence of how TAs reported *responding* to the ideas articulated by students. While we didn't ask the TAs to do this as part of the journal assignment, it is not surprising that they often did given that we engaged in discussions during the PD quite frequently about how to respond to student thinking. As with the interpretations, we found that we could broadly group these response types into two categories (with finer-grained sub-categories also emerging).

Sometimes, TAs reported evidence of a response type that was in line with the principles of responsive teaching that we discussed in the PD. That is, some responses appeared geared towards generating more student thinking and articulations of ideas. For instance, Sadie in week 1 writes about a moment when a student articulated some thinking about bacterial mutation rates:

Another student (it might have been CC again; I don't recall) also asked if mutations that have been repaired still count as mutations. This was an interesting question that I had never considered before. We posed this question to the class and received several responses.

The underlined portion of this excerpt notes Sadie’s reported response to the student thought. Rather than provide a direct answer to the question, Sadie opted to turn the question over to the class and allow for collaboration on the idea. This response is one that we considered to be aimed at generating more student thinking (and as Sadie notes, the move was successful in this regard). We observed sub-categories of this *responsive* response type that involved asking questions, encouraging student-student collaboration and sometimes quietly providing space for students to simply say more.

These ‘responsive’ actions contrasted with the other broad type of response the TAs reported, which appeared to be more aimed at telling students information and/or correcting their thinking. For example, Susan writes about a moment from week 1 when her students were discussing what kind of conditions would favor a high mutating strain of bacteria:

One group was thinking about UV lights. They misread the question and said: “When you are exposed under environment with stronger UV lights, you have more chance to get cancer because your genetic repair mechanism has a higher chance to mutate and becomes dysfunctional. That’s how you end up with a higher mutation.” I realized that they were taking the word “favor” as “cause” but I did not know a good way to correct that. So I simply said: “The question stands for ‘under what condition an organism a higher or lower mutation will have better fitness’.”

Here, the underlined portion shows Susan responding to the students’ thinking by telling them the information she wanted them to know. Unlike the responsive type of responses, Susan does not make any moves to encourage the students to elaborate on their thinking or attempt to drive class collaboration on the idea. She simply provides a statement that she appears to view as a correction to their thinking. These ‘corrective’ responses often involved TAs pointing out flaws and telling students information.

Table 2 below shows the categories of response that we observed consistently across TAs’ journals.

Table 2. Five types of responses TAs frequently described engaging in about moments of student thinking. Bold text denotes the student thinking being noticed; underline denotes the coded response.

Response Type	Description	Example
Providing space for students to think more (Responsive)	This response often involved TAs consciously and intentionally not engaging with students to allow them more time and space to engage in more thinking/articulating.	The students were given very little directions through their discussions and yet topics like genome size, generation time, defining mutation rates, lifespans, and many other topics were discussed. <u>I didn't intrude into any discussions and only listened.</u>
Encouraging collaboration among students (Responsive)	This response often involved TAs turning ideas over to the class or pushing students to talk to one another.	They explained that they thought as resource quality increased, they'd expect more eggs to be laid. From this I got that they were interpreting "x" as number of eggs. <u>I asked the class if this is the way they also interpreted it as well.</u>
Asking questions (Responsive)	This response often involved TAs asking students to expand on their thinking/ideas.	They all had the y axis be the probability of laying an egg/ number of eggs. One group that I talked to had the x-axis be the SA/# eggs already present. This was interesting and <u>I asked them to explain more.</u>

<p>Telling students information (Corrective)</p>	<p>This response often involved TAs actively telling students the answer or specific information.</p>	<p>The class suggested some ideas on how to design an experiment with mutations occurring on the plate, involving more dilutions, replating, and potentially introducing new factors to the plate. I was pleased with this response as it showed a strong problem-solving attitude faced with the challenge of separating mutated cells from within a colony. <u>However, I ended up telling students that as valid as their suggestions were, we would assume that all mutations happened in the subculture tube.</u></p>
<p>Lamenting a missed opportunity (Responsive after-the-fact)</p>	<p>This response often involves TAs being upset that they missed a chance to push on student thinking more.</p>	<p>He was exploring the influence that lethal mutations has on the outcome of the competition. In other words, he wanted to explore whether there was a threshold at which point the high mutator would have the advantage, or if getting any amount of lethal mutations would always favor the low mutator. <u>I wish I had gotten more time to focus on his thinking,</u> but I had to attend to the rest of the class.</p>

For each of the instances in which a TA wrote about noticing a moment of student thinking or idea, we highlighted the student thinking that the TA noticed. Additionally, we

coded the ways that the TAs interpreted those instances of thinking. Finally, we coded the types of responses that the TAs reported implementing with respect to those moments of student thinking. From this analysis, we identify some trends and patterns of interpretation and response that appear to be connected to the experiences that the TAs had as part of the PD.

III. Results

a. Phases One and Two: Characterizing TA Noticing Patterns

We catalogued a total of 100 moments written about across the 38 submitted journal entries from the five TAs. Our focus for this part of the analysis was on identifying how frequently the TAs noticed student thinking. Upon analyzing the 100 moments, we found evidence of TAs noticing student thinking 55 times.

Over the course of the semester (nine weeks in total), Ella and Charlie submitted nine journal entries each, Jake submitted eight journal entries, Susan submitted seven journal entries and Sadie submitted five journal entries. The number of times each TA noticed an instance of student thinking across the semester is reported in Table 3. Keeping in mind the variation in the number of journal entries submitted by each TA, we also report the number of times each TA noticed an instance of student thinking *per journal entry submitted*.

Table 3. Number of times each TA noticed student thinking and the frequency with which that noticing occurred per journal entry submitted for each TA.

TA Name	Total # of Entries Submitted	Total # of Moments of Student Thinking Noticed	Moments of Student Thinking Noticed per Journal Entry
Ella	9	12	1.3
Charlie	9	14	1.6
Sadie	5	8	1.6

Jake	8	9	1.1
Susan	7	12	1.7

The function of presenting this table is to indicate that TAs seemed to notice student thinking with some degree of consistency. In fact, across the 38 total journal entries submitted, TAs noticed either one or two moments of student thinking 32 times. No TA ever wrote about more than three moments of student thinking in a single journal entry (this happened twice) and only four total journal entries included zero moments of TAs noticing student thinking.

As noted above, the heavy emphasis on attending to student thinking and ideas that pervaded the PD leaves us unsurprised that TAs frequently and consistently wrote about moments involving times that they noticed student ideas. Using the journal data to confirm that TAs were able and willing to do this is what ultimately led us to notice the interpreting and responding that TAs also frequently engaged in, patterns that will be explicated on more below.

b. Phase Three: Characterizing TA Interpreting Patterns

Across the TAs' 38 journal entries and 55 moments of noticing student thinking, we coded 36 examples of TAs interpreting student ideas as positive, 3 examples of TAs interpreting student ideas as confusing and 16 examples of TAs interpreting student ideas as incorrect.

Figure 1 shows those interpretations broken down by TA.

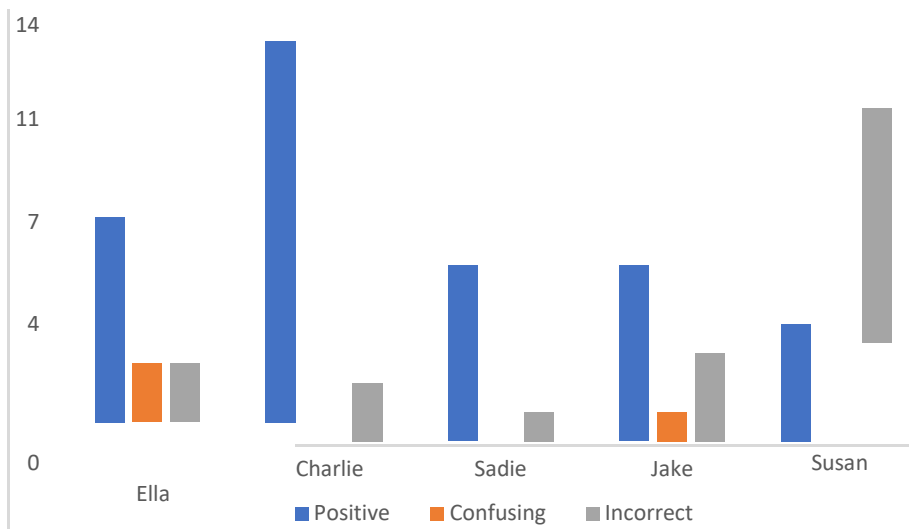


Figure 1. Interpretation types by TA across all journal entries submitted.

c. Phase Four: Characterizing TA Responding Patterns

Across the TAs' 38 journal entries and 55 moments of noticing student thinking, we coded 6 examples of TAs providing space for students to think more, 6 examples of TAs encouraging collaboration among students, 16 examples of TAs asking questions, 8 examples of TAs telling students information and 9 examples of TAs lamenting missed opportunities. The remaining 10 moments of noticing student thinking were not accompanied by reported responses. Figure 3 shows those responses broken down by TA.

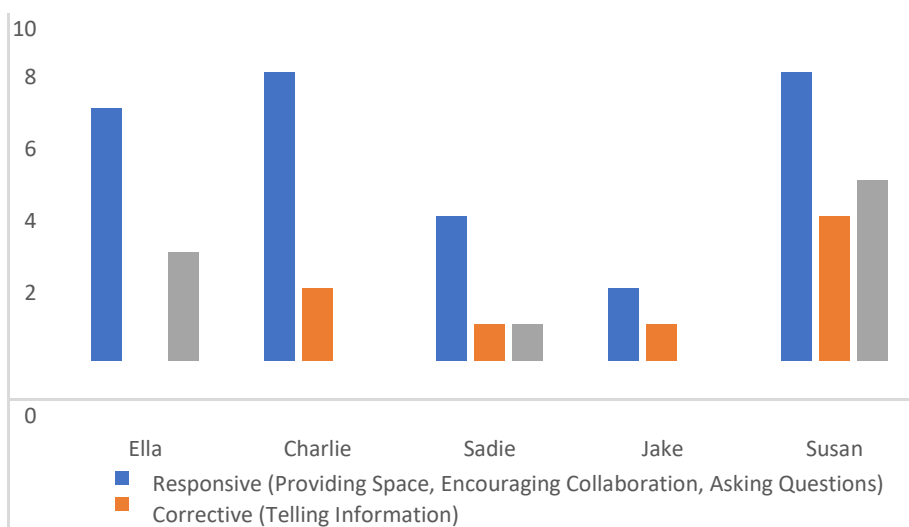


Figure 2. Response type frequency by TA. Responsive sub-categories were collapsed into single categories.

In the next sections we discuss some of the trends that we observed in these data. Specifically, we will examine the general trends of noticing, interpreting and responding to student thinking that occurred across the journal submissions. Following that discussion, we will examine the differences among TAs in these written components of the journals. Specifically, we will conduct an in-depth comparison between three of the TAs. We will explain these patterns in terms of the impact that we believe the journals and the PD at large had on the TAs. Finally, we will highlight one TA in particular, Susan, and some preliminary evidence of pedagogical reasoning patterns that she engaged in to justify her responses.

IV. Discussion

In summary, the data from Phases One and Two of our analysis above show evidence that TAs noticed moments of student thinking and ideas frequently in their journaling. Over half of the moments cataloged by TAs were about student thinking and all TAs wrote on average about 1-2 moments of student thinking in each journal entry (see Table 3). What became of particular interest to us as our analysis progressed was the ways in which TAs reported interpreting and responding to the moments of student thinking they noticed. The ways that TAs interpreted those ideas (Phase Three of our analysis) and the ways they reported on responding to those ideas in the moment (Phase Four of our analysis) were added elements to the journals that we did not ask TAs to include. Here, we provide more details and interpretations of the patterns of how TAs included those elements in their journal entries; we will connect responsive progress that we see the TAs making to their experience in the PD.

a. TA Interpretations of Student Thinking was Largely Positive

TAs tended to interpret student ideas as either positive, confusing or incorrect. Table 1 shows examples of these categories that we observed in the journals. Across the semester, positive interpretations were made almost twice as often as corrective and confused interpretations (36 positive, 19 negative). We believe that this trend is of critical importance for TAs to learn to teach responsively. Previous studies have shown that TAs are capable of noticing student thinking (Levin & Richards 2011; Gehrtz, Brantner & Andrews, 2022), but the way TAs interpret those ideas is quite often with a deficit-based attitude that is focused on what students are missing (Gehrtz, Brantner & Andrews, 2022; Goertzen, Scherr & Elby, 2010). We believe that we see evidence in our data that TAs were not only noticing student thinking but that they were working to interpret that thinking in a positive light. Responsive teaching asks teachers to use the substance of student ideas as the primary fabric of the learning environment. In order to do that, it is critical that teachers can find kernels of student ideas that are worth working with. We believe our TAs showed evidence of doing just that.

For example, in the second week of lab, Charlie's students were discussing the origins and impacts of variable mutation rates. The student discussion went in an unanticipated direction when students began talking about increased mutation rates that occur in humans when familial incest occurs. While this idea was "unexpected" according to Charlie and was certainly not a direction of discussion that came up during the weekly lab prep meeting, Charlie's interpretation of this idea was wholly positive: "It was nice to see students looking through a different sort of lens and it sparked great ideas." It is easy to imagine a much different interpretation of this idea as one that was 'offtrack' or 'missing the point' since the lab was about mutation rates in bacteria and the advantage or disadvantages variable rates of mutation confer.

Instead, Charlie expressed interest in the idea and a general feeling of being impressed that his students came up with a “novel” idea and piggybacked off of each other to generate “great ideas.”

We believe that interpretations like Charlie’s above were made more possible by the conversations that we engaged in during the PD. While watching video clips of students talking, we routinely pushed the TAs to not only identify the student ideas at hand, but to try to find the parts of those ideas that could be used to further the understanding of concepts. This ability to use what students articulate to more deeply engage in content required practice! Especially early in the semester, it was common for TAs to identify student thinking and then judge it as right or wrong. By pushing the TAs to follow up on identifying ideas by trying to locate the parts of those ideas that could be used to responsively teach, we believe that we helped the TAs develop a generally more positive interpretations of student thinking overall.

b. TAs Showed Evidence of Flexibility in Reported Responses to Student Thinking

In terms of reported response patterns, we saw evidence of TAs reporting response types that were responsive or corrective in nature; additionally, TAs sometimes lamented (in their journals) missing opportunities to be responsive (in the moment). Providing space for students to think more, encouraging student-student collaboration and asking questions were generally ‘responsive’ in nature. That is, these responses often appeared to be attempts to get students to engage in more and deeper thinking. The subcategory of ‘telling students information’ was much more corrective (non-responsive) in nature. TAs lamenting missed opportunities was an interesting fifth category of response that was often more self-critical and hypothetical in nature but that was exclusively grounded in wishing that a chance to draw out more student thinking had been seized in the moment.

Ultimately, these different kinds of reported responses indicate that the TAs were able to engage in different kinds of responses (or at least report on different kinds of responses in their journals). This flexibility in response has interesting implications about whether and how TAs were able to respond to context from moment to moment and engage in different ways.

The evidence we see of TAs taking up the responsive types of responses and engaging in them encourages us about the prospect of novice teachers being capable of teaching responsively – with training. While TAs continued to engage in telling students information even up to the end of the semester, we saw more frequent instances of more responsive teaching as well. We also feel it necessary to point out that telling students information is not categorically a *bad* thing for teachers to do. And in fact, it can be effectively coupled with a more responsive move either in the moment or hypothetically. Susan, for instance, in week 5 writes about a moment when one of her students had an idea about selective pressure in plants. This idea did not coordinate with the point Susan was trying to get across to her students about phenotypic plasticity. In the moment, Susan described herself as being “obsessed” with trying to “lead” the student towards her preferred idea and so she “tried to lead” him to it by telling him about plasticity. Within the same journal entry (in fact, only two sentences later), Susan lamented the missed chance to “push his thinking” and indicates that next time she would “ask more” questions to engage him in his idea further. These kinds of moments were very encouraging to us about the TAs’ interest, willingness and ability to engage in responsive approaches to instruction.

c. How Interpreting and Responding Trends Varied Among TAs

Aside from examining the trends of interpreting and responding across all TAs over time, we also chose to look at the individual differences between TAs in their interpreting and response patterns. For the moment, we will leave Susan aside as she showed some unusual

patterns that will be discussed in some detail below. For the purposes of this part of the analysis, we will also largely leave Sadie out as she only turned in only five journals over the 9-week semester. While her data was included as part of the raw numbers, we intend to do a focused comparison below of the remaining three TAs: Ella, Charlie and Jake.

Figure 1 clearly shows that Ella, Charlie and Jake all engaged in substantially more positive interpretations of student thinking than negative interpretations. This pattern is in line with the general trend of twice as many positive interpretations across all TAs. Charlie and Ella most frequently interpreted student thinking in a positive way (13 times for Charlie, 7 times for Ella), which may also be attributable to the fact that they both submitted 9 total journals (while Jake submitted 8).

Where we find the TA-specific patterns more informative is when we look at the response types that TAs engaged in. Figure 2 shows a similar trend in the number of responses: Charlie and Ella most frequently wrote about responses in their journals. But digging deeper into the trends shows some interesting patterns. For instance, Charlie used the response of “asking questions” most frequently (5 of his 10 total responses were this type), and he *never* lamented a missed opportunity. Ella, on the other hand, asked questions, encouraged collaboration and lamented missed opportunities an equal number of times (three apiece).

One interpretation of Charlie’s response pattern is that ‘asking questions’ was his only available move; that is, perhaps Charlie was simply repeating the only move he felt comfortable or able making in the moment. However, we suspect that Charlie’s response pattern may indicate that he was specifically choosing moments to write about that he felt like best demonstrated him doing the things we were practicing in the PD. That is, Charlie may have felt like a ‘successful’ journal entry was one that showed him pushing his students to think more by asking questions. Furthermore, Charlie’s lack of lamenting missed opportunities may not reflect

a belief that there were no missed opportunities, but rather may be evidence of Charlie's interpretation of the journal assignment as one in which to write about successful moments as defined above.

Ella's willingness to lament missed opportunities may have been born out of a different attitude towards the journal assignment. Three times in her journals, Ella wrote about moments that happened which in hindsight, she wished she had focused more on the student thinking and/or had pushed them to articulate their thinking further. In week 4, one of Ella's students proposed an idea about plant opening time. While in her journal, Ella interpreted this idea positively and was pleased with the thinking displayed by the student, she also lamented a missed chance: "I wish I had asked the student to explain a little more [about his idea]." Moments and responses like this indicate to us that Ella was viewing the journal as a tool for growth – commenting on missed chances after the fact and providing hypothetical moves that would have been useful. This contrasts with Charlie who appeared to be more concerned with presenting successful examples of being responsive.

Jake submitted 8 journal entries but only wrote about a response three times total: twice he provided space for students to think more and once he told students information. In the case of Jake, he frequently gave substantial levels of detail about the ideas the students had without writing about what happened in the moment in terms of an interaction with himself as the instructor. For example, in week 6, Jake wrote the following:

One student argued that, "seasonality should play a role in determining how they behavior." Another student argued, "different environments could play a role in predicting this behavior. Some plants could be living in areas with little sunlight and others could be living in areas with more sunlight, which allows for the differences in behavior." The most interesting and most common explanation from an evolutionary perspective was, "the presence of predators determines the speed the of opening in Mimosa and most plants are aware on the trade-offs between collecting resources and

being eaten. The short-day plants don't have a choice and they need to open faster because of the demand for sunlight to meet their physiological needs." I think most students are able to display high level thinking when discussing this topic opening, but they have trouble connecting the biological significance of having a trait that is flexible in any environment. They understand that survival, behavior, and developing multiple traits can give you an advantage, but they can't quite connect why the short-day plants and long-day plants are the same plants but are flexible in their nature.

While there is some judgment present in Jake's writing here about the students missing some connections, there is no mention of how Jake responded to the thinking. Rather, Jake spends most of this entry describing the specifics of the ideas to the point of including quotation marks around his students' ideas. Jake appears to have viewed the journal assignment as a way to reflect and pontificate on the details and substance of student thought.

The response patterns of these three TAs, Jake, Ella and Charlie indicate to us that the teaching journal assignment can be viewed and used in multiple ways – this was something we intended with the design of the assignment. We simply asked the TAs to write about moments that stood out to them about their students. Of course, framed within the context of a PD about responsive teaching, it did not surprise us that the substance of the journals revolved around student thinking. Charlie appeared to view the journal as a way to reflect and report on moments that he felt he successfully engaged in responsive teaching. Ella was more open to using the journal as a way to track her growth and think about more responsive moves she could have made in moments. Jake was primarily interested in using the journals to focus his thinking on the details and complexities of the ideas his students proposed. All of these approaches are valid and carry value for becoming a more responsive teacher! We believe the open-endedness of the assignment gave license to the TAs to use the journals in the way that most aligned with their attitudes and thinking about responsive teaching. Susan, the final TA we will discuss here, used the journals for a decidedly different purpose.

d. Susan and Pedagogical Reasoning

The fifth TA, Susan, had unique interpreting and responding profiles and also engaged in something novel in her journals. Susan was the only TA to interpret student ideas negatively more often than positively. She routinely judged student ideas as missing the point or as being factually inaccurate in her journal entries. However, hand in hand with these judgments, Susan often responded by lamenting a missed opportunity to engage with those ideas. At various points in her journals, Susan notes that her response in the moment was “unprofessional,” she also acknowledges multiple times that she “didn’t know how” to answer a student question in a way that would encourage more thinking in the moment. Often with these judgmental yet lamenting pairings, Susan would also provide after-the-fact examples of what she would do differently if confronted with a similar situation that would allow her to draw out more thinking from her students.

It was this final point that led us to see frequent evidence of something additional in Susan’s journal entries that we did not often observe in the other TAs: pedagogical reasoning. Pedagogical reasoning broadly describes the process by which teachers make decisions about what to do in the classroom (Loughran, Keast & Cooper, 2016; Peterson & Treagust, 1995; Wilson, Shulman & Richert, 1987). Olmstead and Turpen (2017) discuss faculty development opportunities aimed at furthering teachers’ ability to engage in ‘pedagogical sensemaking,’ defined as: “the pursuit of robust pedagogical logic based on observations and interpretations of classroom events.” With regards to Susan’s journals, we considered pedagogical reasoning to be the ways in which she justified the teaching moves she made or hypothetically considered.

In an example from week 3, Susan describes a moment when her students were struggling to come up with explanations for unexpected data from their bacterial experiments. In the excerpt, Susan describes the student ideas on the table, judges the ideas as missing something

and reports responding by asking follow-up questions intended to push the students to think more about other possible explanations. After describing her response, Susan writes:

I feel like if sometimes students have no ideas on what's going on, or they have a rough thoughts but don't know how to purify it to a solid one, it is important to throw questions on them and see how do they react.

This justification for the move that she made was something Susan included in 9 of the 12 moments she describes in her journals. We found it fascinating that Susan felt inclined to include this in her journal as it was more introspective than most of what we saw from the other TAs. Susan's reasoning often included self-reflection (e.g., "I believe that teaching is also a process of learning - not only learning how to teach, but also building my own knowledge based on students' questions and feedbacks") and made us think that she was using the journals as a tool to reflect on her teaching in an attempt to grow and develop.

Olmstead and Turpen (2017) suggest that teachers' abilities to use classroom events as drivers of decision-making are influence-able by facilitated training. The ways in which teachers perceive and react to student thinking are contextually dependent, and the ways in which they justify those perceptions and reactions are likely to be uniquely specific to that teachers' beliefs, attitudes and epistemologies. We intend to further analyze Susan's journal entries and cross reference the moments she writes about with video data of the moments themselves from her lab (see Study Two). In this way, we hope to better be able to characterize the moves Susan made as well as her reasoning for those moves.

We believe our data show that the TAs in our responsive teaching PD frequently noticed student thinking during their labs. Furthermore, we see evidence that the TAs worked to interpret those moments of student thinking in a largely positive way throughout the semester and that they reported on responding to that thinking in a variety of ways that included a suite of

responsive moves. We see evidence for differences among the TAs in terms of how they viewed and used the teaching journals as part of the PD, but across the board those views and uses were grounded in responsive pedagogy. Below, we elaborate on the ways that our PD drove some of these patterns and provide suggestions for how PD can be used going forward to help support teachers' engagement with student thinking and ideas.

e. Limitations of Self-Reported Data

We note here that the source of our data for this analysis – self-reported descriptions of moments – is susceptible to some potential limitations in accuracy. As noted above, the motivations for how the TAs chose to use the journals likely varied among TAs. Similarly, the episodic accuracy of how the TAs reported what they remember happening in their classes likely varied among TAs and even among moments within a single TA's journal. Without video data of all TAs and all moments, we can not be sure if the reports in the journals match what the TAs actually did and the frequencies with which they did those things.

We suggest that despite these potential mismatches of reality and reported moments, the ways the TAs wrote about moments in their journals reflected the ways they were thinking about those moments when they wrote about them. That is, even if the reports suffer from some degree of inaccuracy, we were encouraged to see that the TAs wrote about moments in ways that seemed connected to the principles of responsive teaching we discussed in the PD – noticing, interpreting and responding to the substance of student thinking. The TAs were clearly in the head-space of thinking about these principles with respect to student ideas, whether it have been live in the moment, in recall afterwards, or both.

f. Implications of these Trends for Professional Development

We

believe that our data show evidence that:

- 1) TAs frequently noticed the substance of student thinking and chose to write about moments involving that thinking in their teaching journals.
- 2) TAs interpreted that thinking in both positive and negative ways with a heavier emphasis on positive interpretation of student thinking, an emphasis we believe was a direct result of the PD.
- 3) TAs reported on responding to student thinking in ways that pushed students to think more and in ways that simply conveyed information to students, with the more responsive approach becoming more commonly reported as the semester progressed, a trend we attribute to engagement in our PD.

The first point is self-evident in the data presented above. TAs reported on 55 distinct moments of student thinking. These moments were spread out across all TAs and across all weeks. Journals entries that did not include examples of student ideas were exceedingly rare and the ideas and thinking that were reported on were often written about with a high degree of detailed recall.

Given that the PD these TAs were participating in heavily emphasized the importance of listening for and identifying the disciplinary substance of student thinking, it is not surprising that TAs engaged in writing about these kinds of moments for an assignment that asked them to write about “moments that involve your students.” Despite this unsurprising result, we were still encouraged to see that TAs willingly and frequently took the time to recall and write about specific ideas that their students had in lab. We believe that this attention to student thinking bodes well for the continued noticing abilities of these teachers. Furthermore, that the TAs frequently engaged in following up on the ideas with interpretations and responses is evidence that the concepts of responsive teaching were in the minds of the TAs when they were thinking about and writing about student ideas.

Ultimately, we saw evidence of the TAs' abilities to notice and engage with student ideas in the journals. Over the course of the semester, we saw evidence of TAs interpreting student thinking in a way that gave merit and value to the substance of their thinking rather than simply judging their ideas for canonical correctness. We also believe that the TAs reported on responding to student thinking in a variety of ways, many of which were responsive in nature. We believe that the focus of our PD sessions on identifying the merit of student ideas and engaging with those ideas in productive ways to encourage more thinking was one driver of these trends.

Furthermore, we see evidence that each TA may have used the teaching journals for slightly different purposes. Using the journals to demonstrate responsiveness (Charlie), using the journals to grow and develop (Ella), using the journals to drive specific focus on student thinking (Jake), and using the journals to reason about pedagogical moves (Susan) were all evidenced by our TAs during the semester. Each of these uses carries with it apparent attempts to be more responsive and interactive with student ideas in the classroom.

By consistently pushing the TAs to think about and engage with student ideas in our PD sessions, we believe that the TAs became increasingly willing and able to do this in their classrooms as evidenced by the progression of what they wrote about in their journals. While the journals were used differently by different TAs, we see evidence that the journals were wholly used to focus the TAs' thoughts and reflections on student thinking. These outcomes lead us to suggest the continued use of teaching journals in PD intended to drive more responsive pedagogical approaches. By indicating to the PD participants that the journal entries should be written about moments that involved students, we believe that journals can be a tool that can leverage teachers' focus on student thinking.

While we were pleased with how the journal assignment was taken up by our TAs, we were disappointed that about 15% of the possible entries (7 of 45) were never submitted. For future PD classes, we intend to try to encourage a greater level of participation in the journal assignment. This would not only likely drive more of the outcomes we observed, but would also provide more data for research into the trends and patterns.

One additional aspect of the journal assignment that was not included in this analysis was commentary by the PD instructor. Each week, the instructor of the PD left feedback on the journal entries from each TA. This feedback was designed to encourage engagement on the part of the TAs. For instance, when Charlie described a moment in which his students had a “misconception” about bacterial mutation rates in week 2, the PD instructor left a comment on his journal entry that read: “Can you say more about what that misconception was about?” While the feedback was intended to drive a back-and-forth between the TAs and the instructor, the TAs virtually never responded to the comments. This lack of response makes it difficult to interpret the impact of the feedback, though we suspect that the feedback was likely viewed as reinforcement of the kinds of questions we asked the TAs during the live PD sessions. In future responsive teaching-centered PD, we would mandate that TAs engage with the feedback directly as we believe again that this would not only encourage further consideration of student thinking on the part of the TAs, but would also provide an added level of data for us as researchers.

We believe our analysis shows evidence of the impact that a responsive teaching PD – and specifically the teaching journal assignment within that PD – can have on a population of novice biology teachers. While the evidence suggesting TAs noticed, positively interpreted and responsively responded to student ideas is present, we suggest that some tweaks to the journal assignment could drive even more potential commitment to responsive practices. In further analyses, we will examine Susan as a case study and also conduct a discourse analysis on some

of the live discussions from the PD to further understand how our responsive teaching PD impacted TA pedagogical practice.

Study 2 – Responsive Teaching Professional Development: Examining Noticing and Responding Patterns in a Biology Teaching Assistant

I. Introduction

Research on responsive teaching has shown that by engaging with student thinking and building on student ideas – even ideas with canonical flaws – science teachers can construct classroom norms that encourage more equitable participation (Maskiewicz & Winters, 2012; Warren et al; 2001), increase students’ comfort-level with sharing ideas (Ball, 1993; Hammer, Goldberg & Fargason, 2012; Robertson, Scherr & Hammer, 2015) and generate more authentic atmospheres of students doing science (Levin, 2008). Grinath and Southerland (2019) report that by making ‘ambitious’ teaching moves – moves they describe as being responsive in nature – teachers can drive richer, more rigorous class discussions in which students are more inclined to explain their thinking rather than state memorized facts.

It is hard to imagine education practitioners not being in favor of these benefits of responsive teaching for students – especially as they relate to recent STEM education mandates to expose students to authentic science experiences and enhance the quality of class discussions (American Association for the Advancement of Science, 2010; National Research Council, 2012; Olson & Riordan, 2012).

At the higher education level, introductory science course instructors are often graduate student teaching assistants (TAs). There is clear evidence that what TAs do in the classroom matters for students. O’Neal et al (2007) indicate that science TAs have a direct influence on student lab experience, course grades and even student retention rates in science fields. From a more pedagogical perspective, Grinath & Southerland (2019) studied biology TAs and found that the way they responded to student questions and comments was very important for driving

engagement and directly influenced the explanatory rigor students used when investigating disciplinary concepts.

Recent studies on science TAs specifically have shown that their stated teaching ideologies do not always map directly onto the actions they take in the classroom (Goertzen, Scherr & Elby, 2010; Harlow, 2014; Gehrtz, Brantner & Andrews, 2022). Schussler et al (2008) suggest that TAs tend to be open to considering multiple approaches to instruction. TAs appear to be flexible in how they try to achieve their teaching goals while in the classroom (Goertzen, Scherr & Elby, 2010; Schussler et al, 2008; Grinath & Southerland, 2019). Our goal was to leverage that flexibility within the context of a responsive teaching professional development (PD) to encourage biology TAs to be more responsive in their teaching approach.

a. Professional Development Opportunities for TAs are Lacking

Given the importance of TAs both in their role as novice instructors in fields in which they may continue to teach long-term and also their short-term role as instructors for undergraduate students, one would think that pedagogical training would be a frequent part of the TA experience. Rather, Schussler et al (2015) indicate that training opportunities for STEM TAs are sorely lacking, particularly with respect to pedagogy. Some degree of mandatory and elective training exists for TAs that primarily focuses on lab protocols, content management and grading procedures (Schussler et al, 2015) (much of this training exists in the form of presemester orientations and faculty mentorship). However, specific pedagogy-focused training is generally unavailable to TAs (Schussler et al, 2015). Given the known benefits of responsive teaching for students, and the known lack of pedagogical training provided to TAs, we designed and implemented a responsive teaching-specific PD for biology TAs.

b. Supporting TAs in Learning to Teach Responsively

Noticing the substance of what someone says is a more challenging task than it may first appear. Even in informal talk between friends it is easy to primarily listen for what you expect to hear at the expense of missing out on what the other person actually articulates. Imagine the everyday occurrence of asking someone you know “How are you doing?” The ease with which we simply assume a response of “I’m fine, how are you?” leaves us very open to miss out on a different kind of response or an obvious mismatch between words and tone. As easy as it is to miss something in casual, low stakes conversation like this, it becomes even more difficult to notice the potential disciplinary substance and merit of a student idea within the context of a classroom. Teachers can and do fall into the habit of listening for a specific answer or expecting a particular misunderstanding to arise (see Goertzen, Scherr & Elby, 2010), and in the process they may miss out on the disciplinary meaning or intent behind a student idea or thought.

Listening for the substance of student ideas takes awareness and practice on the part of the instructor; there must be intentionality behind the move of noticing the substance of a student-articulated idea, an intentionality that can be honed through practice (Ball, 1993; Coffey, Levin, Hammer & Grant, 2011; Hammer, 1997; Hammer, Goldberg & Fargason, 2012; Rosenberg, Phelan & Hammer, 2006; Hammer & van Zee, 2006; Richards et al, 2020). The purposefulness that is required to look past what might be considered content ‘flaws’ or ‘misconceptions’ and to focus on the potential merits of the idea has traditionally been considered challenging for instructors (Schoenfield, 1988; Ball, 1993; Goertzen, Scherr & Elby, 2010), but there is evidence that even novice instructors are capable of episodic instances of doing so (Levin & Richards, 2010; Schussler et al, 2015). We designed our PD as a space in which TAs would get ample opportunity to listen to student articulations and practice attending to the substance of ideas with the hopes that this practice would translate into action during their live teaching practice.

Goertzen, Scherr & Elby (2010) conducted a study in which they examined the underlying beliefs about teaching held by a group of physics TAs. The TAs in their study tended to focus on specific indicators of ‘correctness’ in student speech and writing (i.e., looking for the use of particular keywords) (Goertzen, Scherr & Elby, 2010). One TA in particular, Julian, expressed in an interview that he believed his primary responsibility as a teacher was to guide his students toward an “instructionally targeted answer” (Goertzen, Scherr & Elby, 2010). The researchers found that when students were talking with Julian about physics concepts, “Julian’s attention [was] on the precise wording that he expects in the correct answer” (Goertzen, Scherr & Elby, 2010, p. 11). This level of focus on exact, specific instructionally-targeted correctness often led Julian to miss out on attending to the thinking behind a student articulation, thinking that sometimes was very well-aligned with traditionally accepted disciplinary knowledge (Goertzen, Scherr & Elby, 2010). Our PD was intended to introduce a new focus for TAs: the substance of student ideas; and to encourage the TAs to practice noticing and responding to the substance of those ideas by engaging with them in ways that gave students chances to elaborate and build on the disciplinary productive parts.

c. Contribution

While many of the above referenced studies on TA impact and approach have discussed the potential implications for training TAs, our study more closely examines the impact of a specifically formulated responsive teaching PD for TAs. We will use a case study analysis (to be explicated on below) to demonstrate how one TA leveraged aspects of our PD, as well as her own beliefs about teaching and some contextual elements of the lab curriculum, to cultivate a responsive approach to student thinking. We will show evidence that the TA, Susan, took productive seeds of responsiveness in the form of personal beliefs about teaching, and used our

PD and her experience in the lab to germinate those seeds into a more developed responsive teaching technique. We believe our work can offer more direct insights into the affordances a responsive teaching PD can offer TAs as an opportunity for learning and trying new teaching techniques. We will argue that Susan benefitted from the PD by utilizing it as an opportunity to operationalize her beliefs about teaching into practical application in her classroom.

II. Methods

a. Case Selection: Choosing Susan

“I just don’t want, because of my personal experience, to constrain my student’s thinking.”

This quotation comes from Susan, a biology graduate student teaching assistant (TA), during an interview in which she was explaining why she decided to participate in our elective responsive teaching professional development (PD) aimed at encouraging TAs to notice and respond to the substance of student thinking and ideas. Without knowing it, Susan was speaking to the central tenet of our PD: training teachers to build on student thinking rather than constrain it.

In her first interview, Susan demonstrated an interest and personal investment in developing her teaching abilities to avoid constraining students’ thinking. Personal orientation to pedagogical approach certainly varies among teachers; surely Susan and Julian (from Goertzen, Scherr & Elby, 2010) held differing beliefs about teaching. Susan’s orientation was of specific interest to us because of its potential alignment with responsive teaching, which was the foundation of our professional development. We wondered, given Susan’s initial stance, how much progress she could make in developing her responsive teaching approach.

Susan was a first-year biological science Master’s student who was experiencing her first year of teaching. Her TA appointment required that she teach an introductory biology laboratory

for undergraduates in both the fall and spring semesters. Her decision to register for the spring semester PD course was voluntary (and in part justified by her quotation above). Susan's status as a first-year graduate student and first-time teacher made her an interesting case study from our perspective. From her initial interview it seemed apparent that Susan was not yet committed to a particular style of teaching, but was interested in maximizing her students' learning, and limiting herself from constraining their thinking. That is, Susan's initial pedagogical orientation appeared to be laden with seeds of responsiveness.

In addition throughout the semester, we noticed that Susan was very engaged in trying to make sense of student ideas. This interpretation was further supported by an initial analysis of Susan's teaching journal entries.

In their journals, we asked the TAs to "write about a moment from class that stood out to you" each week (see Study 1 for a detailed analysis of the TAs' journal entries). Two things, stood out to us about Susan's journal entries. One was the number of moments that she wrote about. While only being tasked to write about one moment from each week of their teaching, Susan wrote about 23 distinct moments across her 7 journal entries – the most of any of the five TAs (even more than those who submitted more journal entries). We viewed this above-andbeyond approach to the journals as an indicator once again that Susan was interested and committed to developing her abilities as a responsive teacher.

The other aspect of Susan's journals that led us to select her for this study was the high level of introspection that Susan often wrote with. This aspect of her writing was unique among the TAs in our PD. For example, in her fifth journal entry, after writing about some things that happened in class, Susan makes mention of a conversation she had with someone who previously took the course:

When I talk with my friend who took this class years ago, she said that in her lab, after her TA asked a question but nobody answered, her TA just waited until someone was about to talk, simply because students wanted to end this discussion as soon as possible. For me I would feel awkward if I'm standing while all students are looking at me... but I have to admit that it could work sometimes because students might have thoughts but refuse to talk. I don't know if I'll try it - probably not; I'd rather give them some hints, or like what [Jenna] suggested earlier, to put them back in small groups again.

The conversational, introspective tone that Susan writes with here was unique among TAs in the PD. Such entries are evidence that Susan was actively thinking about her teaching. While Susan ultimately indicates that she would be uncomfortable waiting through silence for her students to engage (a notion many teachers would likely agree with), it is her thoughtful consideration of alternative approaches that flagged her as a possible case study for us. In summary, Susan appeared to be a TA who exhibited 1.) an initial orientation potentially aligned with attending to student thinking and 2.) willing to consider and reflect on her teaching. In these ways, we viewed Susan as a good candidate for a teacher who could make progress in responsive teaching. In the remainder of this paper we examine the evidence of this development in the context of our PD.

We will present further evidence from Susan's journals as well as episodes from video of her teaching that we believe indicates she was capable of noticing the presence of student ideas and also of responding to those ideas in a variety of ways. Furthermore, we will present data that we believe indicates growth in Susan over time in her responsive teaching capabilities. Ultimately, we believe that our data suggests that Susan was able to progress from *believing* that student ideas were important to *responding* to student ideas in the classroom in a way that pushed for further thinking.

b. Situating Susan's Experience within Contextual Layers

Susan's personal beliefs about teaching and her stated desire to avoid constraining her students' thinking is one layer of context within which we will try to situate her patterns of

noticing and responding in her class. We suggest two additional layers of context that impacted Susan's actions in her lab: her experience in the PD and the curriculum of the lab that she was teaching. Here we provide context and description on both of those layers. We will then present data from Susan's lab that we will situate within these three layers of context.

i. TA Teaching Assignment: BIO14 Laboratory

Concurrently with our PD, Susan and the other TAs were teaching sections of an introductory biology lab called BIO14: Organisms and Population Biology. Simultaneously with the offering of our PD, the lab curriculum for BIO14 was in the midst of a redesign. The goals of this redesign were to provide students more opportunities to authentically engage in the doing of science by providing opportunities for students to design experiments, interpret results and develop conclusions.

The BIO14 lab curriculum consisted of three model study systems: *Escherichia Coli*, *Mimosa pudica* (sensitive plant), and *Callosobruchus maculatus* (bean beetle). Each model study system was investigated over a three-week period in which the students designed and conducted experiments about the organism, worked with a computer simulation about the organism and then synthesized and analyzed results from the experiments and simulations. Each study system was oriented around an ecological trade-off question:

1. *E. coli*: Is it better to mutate a lot or a little?
2. *M. pudica*: Is it better to forage (photosynthesize) or hide (fold up leaves)?
3. *C. maculatus*: Is it better to lay a lot of eggs indiscriminately, or fewer eggs more choosily?

Teaching this style of inquiry-based lab inevitably led to moments in which the TAs encountered student ideas and questions that were not previously anticipated or prepared for.

These kinds of moments left the TAs in position to make in-the-moment decisions about how to respond, decisions that were undoubtedly influenced by the substance of what they noticed in student articulations. Thus, one question we can ask is how the lab curriculum itself may have influenced Susan's growth and development as a responsive teacher?

ii. *Professional Development BIO196: Student-Centered Pedagogy in Biology*

We modeled several aspects of our PD after previous work that implemented and studied the impact of video clubs (e.g., Sherin & van Es, 2005). We also incorporated elements of previous work that focused on TAs specifically, such as journals (Schussler et al, 2008), interviews (Goertzen, Scherr & Elby, 2010) and classroom observations (Grinath & Southerland, 2019). Ultimately, our PD was grounded in two major activities: watching and discussing video from the TAs' labs and keeping weekly teaching journals. Each of these activities pushed the TAs to practice noticing the presence and substance of student thinking. Getting this practice in a low-stakes PD environment with a community of other TAs created a 'problems of practice' (after Mikeska, Anderson & Schwarz, 2009) atmosphere in which TAs began to feel comfortable discussing their approaches to teaching and the challenges they encountered. One of the benefits of a 'problems of practice' environment is that it treats teachers with respect and empathy, acknowledging that teaching is a challenging professional practice and creating the trust and sense of community needed to make progress in a professional development context (Dini, Jaber, Danahy, 2021; Goertzen, Scherr & Elby, 2010; Mikeska, Anderson & Schwarz, 2009).

Our PD course met once per week for 75 minutes in a classroom familiar to all of the TAs. The course met on Monday mornings, prior to the weekly BIO14 lab section schedule. Given that the lab prep sessions were on Fridays, the TAs in our PD always had both prep and PD prior to their teaching assignment each week.

Concurrently with the PD course, our TAs were teaching sections of the BIO14 laboratory course explicated on above. As part of the PD, we asked the TAs to video record parts of their labs to bring in for discussion in PD. Specifically, we assigned each TA two times during the semester to bring in a short (3-5 minute) video clip from their lab. We instructed the TAs to bring in clips of moments that they found “interesting” or that “stood out” to them. Our PD sessions were then mostly taken up by viewing and discussing these video clips. We (the PD instructors, also the authors of this paper) tried to direct the flow of the discussion towards two main goals: 1) identifying and making sense of student ideas and 2) developing a suite of potential ways to respond to those ideas. During the first half of the semester, we focused primarily on the former and we introduced the later during the second half of the semester.

In addition to bringing in videos from their teaching labs, we also asked each of the TAs to keep a weekly teaching journal. After their lab section each week, we wanted the TAs to write about a moment from that week’s lab that particularly stood out to them. In this way, each TA would build a library of moments from their lab that they noticed. These journals were kept in a password protected google drive folder that the instructors also had access to, allowing for electronic dialogue between the TAs and instructors about the moments that they noticed as the semester progressed.

c. Research Questions

Given our case selection of Susan, and the layers of context within which she was operating as a biology teaching assistant, we will address the following research questions:

- How did Susan’s noticing and responding patterns to student ideas change as the semester progressed?

- How did the contextual layers of the PD, the lab curriculum and Susan's internal beliefs about teaching influence the changes in these patterns?

Below, we provide details of how we collected data and conducted analyses to address this specific research questions.

d. Participants

While our case study will focus on one TA in particular, Susan, the PD course had a total of nine TA participants. All were graduate or undergraduate biological science teaching assistants at a medium-sized private university in the Northeast. Five of the participants (including Susan) were graduate students (Master's or Ph.D. candidates) whose teaching assistantship was awarded as part of their acceptance to the graduate school. The other four participants were undergraduate students who previously interviewed for paid work study positions as teaching assistants.

e. Data Collection

We collected four primary sources of data: TA interviews, PD video, BIO14 lab video and TA journals. Interviews were conducted with each TA between the first and second PD meetings and within two weeks of the final PD meeting. The interviews were semi-structured around two main questions and usually lasted 20-25 minutes:

- What has stood out to you during your experience in BIO196 (PD)?
- What has stood out to you during your experience as a BIO14 instructor?

Interviews were video recorded with consent from the TAs and the video was stored on a password-protected hard drive. All video files were immediately deleted off of devices upon transfer to this drive.

Each PD session was video recorded in its entirety (75 minutes) on a single video camera positioned to capture the whole classroom. All video data was stored on a password-protected hard drive and deleted from recording devices immediately upon transfer to this drive.

We also video recorded the BIO14 lab class meetings for three of the TAs (including Susan) for the duration of the semester. All TAs and students involved in these labs provided written consent to being video recorded, any non-consenting students were positioned off screen of the recordings. Multiple cameras and audio recorders were set up in the lab rooms to capture whole class vantage points and also smaller group-focused recordings. TAs in these recorded labs wore lapel audio recorders as well. A researcher was present during these recordings to keep field notes on what was going on in the labs and to manage the recording equipment. Each lab section lasted about three hours. All video and audio data were stored on a passwordprotected hard drive and files were deleted from devices upon making the transfer to this drive.

Details of the TA weekly journals were explained above in Study One, here we simply note that all journal entries were stored on a password protected drive and all TAs consented to the journals being used for research and potential peer-review publication purposes.

f. Data Analysis

Our primary analytic goal was to characterize Susan's noticing and responding patterns. Our study is aimed at explaining *what* Susan noticed in her students and *how* she responded to those things she noticed. As such, we primarily analyzed two sources of data for this paper: Susan's journal entries and the classroom video from Susan's lab section.

i. Characterizing Susan's Noticing Patterns

To make sense of Susan's noticing patterns, we turned to her journal entries as these were moments that 'stood out' to Susan enough for her to write about after her lab. We first read

through each of her seven journal entries and wrote qualitative memos about the substance of her writing. Following this broad-strokes characterization of each journal entry, we identified ‘moments’ that she specifically wrote about. In her seven journal entries, Susan wrote about 23 distinct moments. For each of these moments, we first determined whether it was studentcentered or focused on something else. For instance, in her journal for the second week of *E. coli* lab, Susan wrote the following:

Instead of having 0-1 colonies on the low mutator rif+ plate, the whole class ended up with nothing. I was worried that they would simply consider that low mutator strain is unable to survive in such an antibiotic environment at all.

This moment that Susan described was not coded as ‘student-centered’ because rather than focusing on an idea or thought that a student articulated or generated, Susan focused on an anomaly in the data from her lab. That is not say that this was an unimportant thing for Susan to notice or that it was unreasonable that this stood out to Susan from that week of lab, but for the purposes of understanding the impact of our responsive teaching PD, we tried to distinguish between times in which Susan noticed something about her students and other things. As an example of a moment Susan wrote about that was student centered, we can look at moment 19 from Susan’s week seven journal (beetle lab):

After I asked them to consider how did lines intercept with x- and y-axis mean, she said: “Line intercepts with y-axis may imply a harsh environmental condition where female maximizes her fitness by laying eggs in spite of resource quality. Line intercepts with xaxis may imply a good condition when female maximizes her fitness by comparing resource quality and doesn’t lay eggs until she finds a resource with certain level of quality.”

Here, the substance of what Susan wrote about is literally her memory of an idea proposed by a student in response to a question she asked the class. For the 23 times that Susan wrote about noticing something student-centered, we then tried to determine whether Susan was focusing on an idea (like the moment above) or whether what stood out to her was something

else about her students. Sometimes, the student-centered thing that Susan was attending to was more affect than idea-based. For instance, in moment 11 (week one of plant lab), Susan noticed and wrote the following in her journal:

I know the group at the front close to the door had disagreement or confusions because they were not certain of either answer, and I believe that there should be some other groups or students confused too.

In this instance, Susan was noticing things about her students, but rather than keying in on a specific idea or thought that a student had, she noticed their affective stance of being ‘confused’ and indicated that she thought other students would feel similarly.

Our goal with our analysis of Susan’s journal entries was to first characterize and categorize the kinds of things that Susan noticed while teaching her lab section. Our main focus was to understand how Susan noticed and engaged with students’ disciplinary thinking.

ii. Characterizing How Susan Responded to Student Thinking

Our remaining analysis will focus more specifically on the twelve times that Susan noticed a student *idea*. Her attention to these instances of student-articulated, discipline-based thinking varied in flavor in terms of the context within which she noticed the idea. Sometimes, she reported a value-judgement with her noticing, indicating that she picked up on the idea because of a canonical flaw. For example, in moment two (from week one of *E. coli* lab), Susan wrote the following in her journal about the moment that stood out to her:

[T]he [student] said that only mutator strain could mutate but standard strain couldn’t mutate, because standard strain had a functional repair mechanism that could recognize errors and fixed them. I realized that he misunderstood the definition of repair mechanism.

Here, Susan first reports the idea she noticed the student articulating: “only mutator strain could mutate but standard strain couldn’t mutate.” The thing about this idea that stood out enough to Susan for her to include in her description of this moment was her realization that the

student “misunderstood” a definition. This is in contrast with other times that Susan noticed student ideas and what stood out to her in the moment was something less evaluative in nature. For instance, in moment 21 (from week 1 of bean beetle lab), Susan reports on students proposing an idea more descriptively, without a value judgement of the content of the thinking:

“[The group of students] said that they thought the inconsistency of the result might be because the model evaluated bean quality with bean mass. They believed bean surface area would be a better representative than bean biomass in terms of evaluating bean quality because there’ll be more eggs laid on beans with more surface area instead of more biomass.”

In this instance, Susan writes about an idea that students proposed that came from their use of a computer simulation: “They believed bean surface area would be a better representa[tion] than bean biomass in terms of evaluating bean quality.” This idea was born out of a discussion between Susan and the group of students about some results from the simulation that were inconsistent with their expectations.

In moment 2, Susan follows up her noticing of the idea by evaluating it and commenting on a flaw in the idea. In moment 21, Susan provides no such evaluation and simply reports on the existence of the idea. Another example, moment 15 (week 3 of sensitive plant lab), shows Susan noticing student ideas and providing a valuation of those ideas – but with a very different affective attitude than in moment 2:

Students brought up various point on [why adaptation is limited]! In lecture they have discussed the idea of physical constraint, which is the idea raised in prep, and I’m glad that students also applied it to explaining plant behavior

In this example, Susan notes that when confronted with a broad question (about limits to adaptation), her students “brought up various point[s]” and were able to apply one particular point to the experiments they were conducting about plant behavior. Susan clearly has a positive feeling about what happened in this moment and reports on being “glad” to see the students engaging in this way.

What helped drive this layer of analysis was the myriad of ways that Susan self-reported responding to the ideas students proposed. Rather than rely solely on Susan's self-reporting to characterize her responses, we turned to the classroom video from Susan's lab. After using her descriptions of moments in her journal to locate those moments in the video (12 in total), we used a qualitative analysis of transcript to describe and characterize the ways in which Susan responded to those ideas in the moment. The approach to and substance of this analysis will be exemplified and analyzed in the following section.

III. Susan's Noticing Patterns

Susan wrote about 23 distinct moments (as described above) in her seven journal entries for the semester. Of the 23 moments described by Susan, 21 of them were student-focused. The two non-student-focused moments included times in which Susan wrote about a data anomaly that she found interesting (this moment was referenced above in the methods) and a dispute between her and her undergraduate teaching assistant about distributing class materials.

Within the 21 student-focused moments that Susan reported on in her journal, she noticed a student idea twelve times ; in these moments, the substance of Susan's noticing was focused on a student-articulated thought or idea grounded in biological disciplinary content. Five times within this student-focused nest, Susan reported on general levels of student participation; that is, she noticed the presence or absence of student talk during lab (but without specifics on content). Four other times, Susan wrote about student affect; sometimes these moments involved Susan noticing student frustration or confusion, other times she noticed student excitement or contentment. Overall then, more than half of the moments Susan chose to describe were about a students' disciplinary idea.

IV. Susan's Responses to Student Thinking

Below, we present transcript of some selected moments of Susan responding to student ideas that she noticed and wrote about in her journals, use the content of these transcribed moments to characterize Susan's responses to student thinking. We found that Susan's responses fell into two broad, coarse-grained categories:

1. *Directing or correcting student thinking.* In these instances, Susan made moves to either direct a student idea towards her own thinking, or to outright correct a flaw she perceived in the thinking.
2. *Questioning or encouraging student thinking.* In these instances, Susan made moves to either ask follow-up questions or to encourage further discourse on a student idea.

While we certainly would consider the second category of moves more "responsive" in nature, we want to emphasize here that *all* of the moves Susan made were responses to moments of student thinking that Susan attended to. That is, one could argue that by simply noticing and responding to student thinking, Susan was engaging in responsive teaching. What we will argue here is that the second category of response is more in line with what our professional development was encouraging the TAs to engage in; questioning and encouraging further student thinking was a move that often led to increased space for students to engage more deeply with the science. Bishop (2021) used qualitative coding of classroom discourse to examine the degree of responsiveness of teachers' moves. 'Lower-level responsiveness' often centered the teacher's ideas or focused on correcting students (Bishop, 2021). 'High-level responsiveness' included moves like asking probing questions, revoicing student thinking, or engaging students with a peer's idea (Bishop, 2021). These moves engaged with and explored student thinking. We consider the second category of response to be more *advanced* or *refined* responsive teaching.

a. Examining and Contextualizing Susan's Responses to Student Thinking

i. *Moment 1 – UV Rays Example*

In Moment 1 (which came from Week 1 of BIO14), students were working on a worksheet that was asking them to consider what environmental conditions would favor an organism with an abnormally high rate of mutation. In her journal, Susan wrote the following description of the moment:

I walked around and asked each group for their thinking. One group was thinking about UV lights. They misread the question and said: “When you are exposed under environment with stronger UV lights, you have more chance to get cancer because your genetic repair mechanism has a higher chance to mutate and becomes dysfunctional. That’s how you end up with a higher mutation.” I realized that they were taking the word “favor” as “cause” but I did not know a good way to correct that. So I simply said: “The question stands for ‘under what condition an organism a higher or lower mutation will have better fitness’.”

Broadly, Susan is describing a moment in which she interpreted students’ thinking as a misunderstanding of the question. The students indicated that exposure to ultraviolet light would increase mutations and therefore would be conditions that satisfied the question. This idea is somewhat removed from the prompt of describing conditions that would *favor* high mutation rates rather than *cause* them. We draw attention to Susan’s line in this journal excerpt of “I did not know a good way to correct that.” With this line, Susan is indicating several things:

1. She has noticed something (“that”) in the students’ idea
2. She believes the thing she has noticed requires “correction”
3. She doesn’t know how to engage in the response (“correcting”) that she believes is needed

Susan follows up this line with her recollection of what happened. She rephrased the question from the handout while emphasizing the part the students seem to have misunderstood.

After reading her journal account, we went to the video of the moment to see how she actually responded when this instance occurred. The transcript of the moment follows, along with some qualitative commentary.

Susan: So what is the condition of the environment?

Kevin: UV rays!

Susan: So, UV rays...what?

Kevin: Increases mutation.

Claire: It would increase mutations.

Susan: Uh huh. So, why?

We notice that so far, Susan has actually only asked questions. She seems unsure of what the idea really means at first. When Claire explains that UV rays would “increase mutations,” Susan simply asks “why?” This initial instinct to make an effort to understand the students’ idea is an early kernel of responsiveness that impressed us.

Kevin: It breaks the bonds, the disulfide bonds!

Erin: Disulfide bonds?

Kevin: It does something with the bonds...

Erin: I don’t know, I’m just making up bonds right now. Is that even...?

Kevin: It does something with the bonds, we know that.

Susan: So do you mean like UV, like UV lights would...favor mutations?

Kevin: Yeah.

Erin: Yeah.

Here is where Susan’s reporting of the moment in her journal seems to match the reality of the moment. Susan seems to pick up on the fact that the students are not really addressing the question of ‘what conditions favor mutations’ and here she clearly is trying to lead them back to that origin (as she reports in her journal).

Susan: So it’s like, if you...

Kevin: If you're in the sun, you get skin cancer.

Susan: Ok...

Kevin: That's my example.

Susan: Let me think about it.

Susan: So maybe if you mutate faster then you'll be favored under stronger UV light? Is that what you're saying?

Here, we see some deviation in response from what Susan reported. Remember, in her journal, Susan indicated that when she realized her students were misunderstanding the question, she wanted to correct their thinking but wasn't sure how and therefore just "told" them a rephrased version of the question. Here, though, Susan (after asking for a moment to consider Kevin's example) takes up the students' idea about UV light and asks whether they are considering that idea with the notion of "faster" mutations being favored. We view this response as different from "telling" the students the correct interpretation of the question.

Claire: Yeah...well I mean, I guess if you have no exposure versus like constant exposure, you'd be more likely to get skin cancer.

Susan: Uh huh...like if you are exposed to stronger UV lights then you are easier to get cancer, but if you mutate faster than you are not going to get cancer? Is that what you are saying?

Kevin: More UV light is gonna just...

Erin: What we are saying is that if you are exposed to more UV light, you are more likely to get cancer.

Susan: So UV light causes the mutation?

Kevin: Yeah.

Erin: Yeah.

Claire: Yeah.

As this moment concludes, we still see Susan working to both understand the idea ("Is that what you are saying?") and also to incorporate the idea into her understanding of the question "...but if you mutate faster then you are not going to get cancer?").

1. *The Influence of the BIO14 Curriculum on Susan's Response*

Given the stated goal of the BIO14 lab curriculum to push students to engage in the doing of science, it is not only conceivable, but probable, and even intended, that the labs would draw out student ideas and thinking. We wondered if the disciplinary uncertainty inherent in these kinds of lab activities could also have been responsible for pushing the TAs to be more responsive in their approach. That is, while being faced with more instances of overt student ideas may have contributed to more instances of TAs like Susan noticing and responding to those ideas, we also believe that the nature of the lab curriculum pushed the TAs to focus in on student ideas more.

In this first moment, the students are navigating an early attempt at articulating their own discipline-based ideas to Susan. We can see uncertainty from the students early in the moment as they try to communicate their idea. The point of the worksheet was to push students to think about a complex biological phenomenon (mutation rate as it relates to natural selection) and to give them an opportunity to address some open-ended questions. While there may not have been a singular 'correct' answer to the question, there are canonical ideas that could be applied to this question, such as, the prediction that harsh or changing environments would favor a higher rate of mutation. Further, we would expect that TAs were aware of these canonically accepted arguments.

The context of this moment happening early in the semester as an activity to push students to engage with some disciplinary uncertainty may have contributed to Susan feeling the need to nudge students towards the intended direction. Providing space in this moment for the students to pursue their original line of thinking about factors that *cause* mutation, could have set an early precedent in the classroom that going down any tangential line of content to the topic at hand was to be considered productive. Susan may have felt that so early in the semester, it was

important to set boundaries about how to engage with content in a canonically meaningful, productive way.

2. The Influence of BIO196 on Susan's Response

The overarching goal of our professional development was to give TAs a low stakes environment in which they could practice noticing and responding to student thinking. We asked the TAs to engage with this practice of responsive teaching both through discussion of video clips and also by keeping a teaching journal during their experiences teaching the BIO14 lab.

Early in the semester, our PD focused primarily on identifying and noticing the substance of student ideas. That is, we overtly did not spend time crafting responses to student thinking, but rather worked collectively to observe moments of students engaged in content and identify and articulate the substance of their thinking and ideas. Susan's selection of this moment and her re-creation of it in her journal are evidence that she was engaged in this type of task. We consider Susan's noticing of this moment to have been supported by her practicing noticing in the PD. Susan's response in this moment is more likely to have been influenced by her own internal motivators and the lab-context of the moment given that we had yet to discuss or practice responding in the PD.

3. The Influence of Susan's Beliefs about Teaching on her Response

Keeping in mind that this moment happened at the very beginning of Susan's teaching assignment, we can best explain Susan's internal beliefs about teaching from her initial interview in which she expressed the desire to teach in ways that avoided "constraining" her students' thinking. Susan's probing questions in Moment 1 are evidence of her attempting to understand students' ideas. Even after Susan appeared to have a handle on the idea, she continued to express thoughtfulness and consideration of the thinking in the interaction.

We would expect that as Susan progressed through her semester of PD and BIO14, that her internal beliefs and motivators about teaching might adapt in ways that are reflected in her practice. This initial response to a student idea that was deviated from expectations showed Susan's commitment to her instinct of wanting to give students space to think aloud and articulate their ideas without feeling constrained. This moment may have represented a moment of tension for Susan; she did not want to constrain her students' thinking, but she also did not want them to be answering the 'wrong' question. The elements of responsiveness that she engaged in in this moment show her attempts to reconcile that tension.

4. Seeds of Responsiveness Present in this Moment

In this episode, Susan attempted to transform students' ideas to match her understanding of the question they were meant to be answering. The idea of ultraviolet light was not one that came up in lab prep; it is unlikely Susan was prepared to consider this as an answer to the question on the worksheet. Again, while she could have (and seemed to report in her journal that she did) simply corrected the thinking by moving away from this idea of something that causes mutations, she instead worked to try to incorporate the idea into her understanding of the question. The awareness on the part of Susan to not shut down the idea hinted at more advanced responsiveness than she ultimately showed in the moment; while she did try to steer the idea, she also made a concerted effort to notice and engage with it.

This moment occurred during week one of the semester, after Susan had participated in only one responsive teaching PD session. While we view this response from Susan as a more basic form of responsiveness, and we agree with her journal report that she primarily was focused on re-directing the students' thinking towards a more canonically correct understanding, we also see kernels of more advanced responsiveness. The work Susan put in to understanding the students' idea, the thoughtful questions she asked the students to gain that clarity, and her

continual effort to incorporate parts of the students' idea into her re-directing of their thinking indicated to us that Susan had some pieces in place to develop a more advanced responsive pedagogical approach.

Specifically, we see evidence from this moment that Susan incorporated the following 'seeds of responsiveness' into her pedagogical approach:

- Asking questions (e.g., "So maybe if you mutate faster then you'll be favored under stronger UV light? Is that what you're saying?")
- Re-voicing student ideas (e.g., "if you are exposed to stronger UV lights then you are easier to get cancer, but if you mutate faster than you are not going to get cancer?")
- Putting in effort to consider student ideas (e.g., "let me think about it")

This moment must be considered within the contextual layers of the BIO14 curriculum, Susan's experience in BIO196, and Susan's internal beliefs about teaching. Given that the moment was early on in the semester and students were likely still finding their footing with the inquiry-based style of lab, it was encouraging to see Susan responding to their uncertainty by asking questions to get clarity on their idea. Given that Susan had only experienced one week of BIO196 which was primarily focused on identifying student ideas in video, we were excited to see her making a responsive move like re-voicing the students' language in her interaction with them. And in light of Susan's stated goal of avoiding putting limitations on her students' ideas, it made sense to see Susan be very obvious in her consideration of their thinking in this moment. We suggest that as we present analysis from the next moments below, we see evidence of these seeds of early responsiveness germinating into a more full-blown responsive approach from Susan.

ii. *Moment 2 – Mutator Example*

In the second moment that we present here, Susan reports in her journal about a moment in which a student is trying to explain whether and how high and normal mutating strains of

bacteria would grow on plates containing antibiotics. This moment occurred during the second week of lab. Susan's journal of this moment was written as such:

I asked the class what they would expect on two antibiotic plates. One student said the mutator strain would have colonies on rif⁺ plate but the other wouldn't. Then I asked him to further explain, and he said that only mutator strain could mutate but standard strain couldn't mutate, because standard strain had a functional repair mechanism that could recognize errors and fixed them. I realized that he misunderstood the definition of repair mechanism, so I told him that even a fully functional repair mechanism also made mistakes, just fewer. And he changed his mind saying that mutator strain would have more colonies than standard strain on antibiotic plates.

After locating this moment in the video files from Susan's lab sessions, we transcribed the interaction Susan noticed between herself and a student. Below is the transcript along with some analytical commentary about Susan's responses to Jaren and the general nature of this interaction.

Susan: So what would you expect, on the mutator strain, then, compared to the standard strain? What would you expect to see? On the agar plate? Yes (calling on a student with raised hand)?

Here Susan is asking the whole class to make predictions about how the two strains of E. coli (a standard strain and a mutator strain that has an abnormally high rate of mutation) would grow on petri dishes prepared by the students (one with only agar and one with agar and rifampicin, an antibiotic that is lethal to standard E. coli).

Jaren: So, I was gonna answer but you asked another one, but I guess the same amount of growth as the regular.

Jaren indicates that he was going to answer the question with respect to the rifampicin plate, but given Susan's pointed question about agar, he believes both strains would grow "the same" on a plate without antibiotic.

Susan: So what about the rif plate?

Jaren: Um, well, the normal cells would die, but that mutation one, the mutation strain would still remain.

When prompted by Susan to predict what would happen on the rifampicin plate, Jaren suggests that all of the standard strain ("normal cells") would die and the high mutator would survive.

Susan: But, just, so you mean the whole standard strain would die? Or...?

Here is the first evidence that Susan may be keying in on a perceived flaw in Jaren's idea and responding in a way that is pushing Jaren to think differently. In the video, Susan emphasizes the word "whole" here, seemingly to determine whether Jaren thinks all standard strain would die on a rifampicin plate.

Jaren: I think so, I don't really know.

In the video, Jaren seems a bit discouraged by Susan's question. Rather than expound on his first response, Jaren expresses uncertainty and then seems to wait for Susan to provide more information before he commits to a response.

Susan: Because, because what we want to say, what I want to say is that even the standard strain is, the normal one, it will still mutate. Just like they have a lower mutation rate than the mutator.

Susan's response here is one of 'telling.' After Jaren expresses uncertainty, Susan simply informs him (and the class) that the standard strain still mutates, just not as much as the mutator strain. This response aligns well with how Susan reported on this moment in her journal: "I realized that he misunderstood the definition of repair mechanism, so I told him that even a fully functional repair mechanism also made mistakes, just fewer." Given that Susan noticed the presence of Jaren's idea, and keyed into a flaw in that idea, Susan's response here can be characterized as 'correcting a flaw' or 'telling the answer.' Susan wanted her students to understand that mutations happen in both strains, and so that's exactly what she told them.

Jaren: Oh.

Susan: So what will happen?

Jaren: You'll still see some standard strain there, just not as much as the mutation strain.

After making clear the piece of information that she wanted her students to know – that both strains mutate – Susan prompted Jaren to answer the original question, what will happen on the rifampicin plate. Jaren obliges by 'changing his mind' (as Susan notes in her journal) and suggesting that both strains will grow on a lethal plate, but the one with the higher mutation rate will grow more. This answer is one that the TAs came to in lab prep and determined that they wanted their students to come to this as well. There may have been opportunities during this interaction for Susan to push Jaren on his original idea (of standard strain dying). It's actually not clear if Jaren ever believed that all standard strain would die. But instead, she corrected the flaw, and gave Jaren a chance to voice the 'right' answer.

1. The Influence of the BIO14 Curriculum on Susan's Response

Much like Moment 1, this moment happened early in the semester of BIO14 (week 2). We again suspect that students were finding their footing with being asked to articulate thinking and generate ideas about disciplinary concepts. Jaren's hesitation is obvious throughout this episode and perhaps contributed to Susan's selection of the moment to write about in her journal. The way Susan writes about this moment seems to reflect that she remembered it as an opportunity to help correct Jaren's 'misunderstanding' about mutation mechanisms; she then notes at the end of her entry that after their interaction, the student 'changed his mind.'

Given the early point in time of the semester, it is possible that Susan felt the need to make moves in this episode that helped keep Jaren on the right track with content. She provided a direct articulation of the point that she thought the student was missing and then essentially asked the student to incorporate this point into a new, 'correct' answer to the question at hand. Common within both of these first two moments is the clear feeling of uncertainty among the students articulating their ideas. We see this theme as one that maps logically on to what the lab curriculum was pushing the students to do: engage more conceptually-deeply in the science. If this was a new experience for the students (and we suspect it was), it is not unreasonable that they might feel uncertain in articulating their ideas. Early in the semester, Susan appears to have picked up on that uncertainty as a cue for selecting moments to write about. In her interactions, we can imagine that the uncertainty being communicated by students put Susan in a place to feel like she needed to help provide clarity and more of a sense of certainty around concepts and assigned questions.

We also note that during the lab prep session prior to this week's lab, the TAs had come to a consensus about the science behind this concept. During the session, the TAs discussed what they expected the data to show and collectively determined that it would make sense for

both strains to survive the competition though at variable levels. We believe that coming to class armed with this knowledge, Susan may have found it easier to encourage Jaren towards the correct prediction.

2. *The Influence of BIO196 on Susan's Response*

Through the first two weeks of the BIO196 PD course, we as instructors of the course often found that we had to make a concerted effort to encourage the TAs to shift their focus away from the canon of the disciplinary substance being discussed and towards parsing out the meaning of student ideas. That is, it was common practice in the PD during the first few weeks for the TAs to get caught up in debating the science with each other – conversations that often resulted in a temporary neglect of the actual student idea on the table.

For instance, in week one of the PD, the TAs got embroiled in a lengthy discussion about the timeline of *when* mutations occur during the experimental protocol being used in the lab for the *E. coli* bacteria. This discussion took the TAs out of the ‘mode’ of identifying and articulating the ideas students were sharing in video. We as the PD instructors consciously and overtly pushed the TAs back towards a discussion about student thinking by saying things like: “Wait, but what about the idea the student is sharing in the video? Can anyone articulate the thinking there?”

In this moment with Jaren, we see Susan engaging in perhaps her most directive approach to a student idea. She recognizes a flaw in the canonical science that Jaren is talking about and pushes him towards a more accepted understanding of mutations between bacterial strains. As we will note below, we do still see some seeds of responsiveness in Susan’s approach – and simply by reacting to Jaren’s idea, one could argue that Susan is being responsive. But this

reaction with respect to the canon is reminiscent of some of the discussions we observed in the PD early in the semester.

We would also be remiss if we did not note here that it is very conceivable that Susan's reaction to the canon and directed response to Jaren may very well have been the most productive kind of response in this moment! It is not our contention that a "good" teacher is entirely openly responsive to every statement a student makes. In fact, we believe that contextualizing responsive engagement with student ideas is not only practical, but perhaps reflective of the most advanced kind of responsive teaching. Being able to recognize when it is productive to engage students in elaborating on non-standard thinking and when it is more productive to help encourage a return towards the canon is a level of responsive teaching that is difficult yet stands to be highly effective.

At this point in the semester, we attribute Susan's basic responsive engagement with Jaren's idea here more to her limited exposure to responsive practices than to this high level of discernment; but we also propose that discernment can develop over time, and this may be an early example of Susan showing preliminary evidence of that ability.

3. The Influence of Susan's Beliefs about Teaching on her Response

As with her engagement in Moment 1 about the UV ray idea, we see continued evidence in this moment with Jaren of Susan making efforts to not shut down student thinking. Jaren's hesitation, coupled with Susan's directed response leads to a flavor in this moment of 'the teacher correcting the student.' And Susan does report in her journal that after the interaction, she noticed that Jaren 'changed his mind' to the more canonically acceptable understanding of the concept. But we also see Susan asking Jaren questions, as opposed to outright telling him facts.

We also note that at the end of this interaction, Susan pointedly gives Jaren an opportunity to re-articulate his idea: “So what will happen?” Once again, considering Susan’s contention that it is important to give students space to think, we might read this question as evidence of Susan giving Jaren a chance to articulate his thinking on the topic of mutators after having a conversation with the teacher. Susan could have just as easily simply summarized the idea herself and moved on; by giving Jaren the chance to do that work, we suggest that her beliefs about non-constraining teaching are shining through again.

4. Seeds of Responsiveness Present in this Moment

In this moment with Jaren, we see perhaps the least responsive approach by Susan of any of the examples we will present. Very early on in the interaction with the student, Susan picks up on a canonical flaw in Jaren’s thinking and pushes him towards a different understanding that more closely matches the standard disciplinary knowledge. Examining this moment, however, does reveal some interesting seeds of responsiveness. When Jaren articulates his initial idea about which bacteria will die on the plate, Susan prompts Jaren to say more by asking him questions. In fact, during the interaction, Susan’s first three utterances are all questions. She asks him what he thinks will happen “on the rif plate,” and she asks him if he thinks the “whole standard strain will die” and then leaves him space with an open-ended questioning, “Or...?” To be clear, we recognize that each of these questions are evidence of Susan trying to help move Jaren towards the answer that she was looking for – an approach that is decidedly lacking in responsiveness. But we would also argue that we see this example as a place where an instructor could have approached Jaren’s idea with a much heavier hand. Susan gives Jaren agency over his idea with her question of “do you mean the whole standard strain would die?” An alternative approach in this moment could have been to say something more along the lines of “Remember,

the standard strain mutates too, so those bacteria that mutate and develop an effective mutation would still survive – just at a lower proportion than the high mutator strain.”

Again, we recognize that Susan did move towards this type of reply in her interaction with Jaren in this moment. But we also see evidence of her attempting to avoid the heavyhanded correction that would ultimately stand to ‘constrain’ thinking in the classroom. By interrogating Jaren’s idea instead of dismissing it, Susan showed more evidence of possessing – and implementing – some seeds of responsiveness in her interactions with her students. Specifically, we see evidence from this moment that Susan incorporated the following ‘seeds of responsiveness’ into her pedagogical approach:

- Asking questions (e.g., “so you mean the whole standard strain would die?)
- Giving space for Jaren to re-articulate his idea (e.g., “So what will happen?”)

When considering the context of the moment within the scope of BIO14, BIO196 and Susan’s own beliefs about teaching, we view this moment as another example of basic responsiveness that contains seeds of a deeper, more advanced responsive approach. We will present evidence from two more moments of Susan’s lab that we believe show those seeds germinating into a more advanced approach to responsive teaching.

iii. Moment 3 – The Panda Example

In week six of the semester (final week of *M. pudica* lab), Susan introduced a whole class discussion centered on the question of why all traits in organisms haven’t adapted to be maximally optimal. In her journal about this moment, Susan wrote:

Students brought up various point on that! In lecture they have discussed the idea of physical constraint, which is the idea raised in prep, and I’m glad that students also applied it to explaining plant behavior.

Below is the corresponding transcript and some interspersed commentary about this moment and Susan’s responses to student articulations.

Alex: We talked about historical traits in, er, historical constraints in class. Which, like, I forget the actual definition, but –

Susan: You can just use your own words.

Alex: Yeah, as, as, an organism's evolving, like through natural selection or whatever, like sometimes these maladaptive traits can stop or like kinda feedback on beneficial traits or things...

So far, Alex is attempting to articulate an idea that addresses a class question about why all traits wouldn't be adapted for maximum success. He brings up the notion of 'historical constraints' as something he learned about in the lecture component of BIO14. Susan encourages him to try to articulate the idea in his own words.

Susan: It means like, sometimes maybe the trait is not that bad?

Here, Susan is trying to make sense of Alex's idea. Her tone is one of uncertainty; she lacks clarity on what Alex means and is wondering if his idea is about the degree of impact of a trait. Her response here is in the form of a question, giving agency to Alex to try to explain.

Alex: Honestly, I don't really remember. The example we went over in class was like the panda example of having, like it doesn't have an opposable thumb but it has all of its fingers on top of the hand instead. So just like, that's the way it evolved.

Susan: Like, his- his- historically?

Alex: Yeah, I don't know. That's just one of the constraints we talked about in class.

Alex attempts to relate his idea to a specific example from class – panda fingers. He explains his understanding of how historical constraints on a panda mean that it can't evolve opposable thumbs. Susan takes up his language (she has never mentioned historical constraints in lab) to continue to try to get Alex to clarify.

Susan: Mhmm. And you are all in the same class, so can anyone remember the definition?

Alex: Yeah.

Susan: Can anyone like, reiterate what he just said?

It still seems like Susan is not totally understanding Alex's idea. And yet, she continues to make moves to try to understand. Twice here, she turns the idea over to the class. She asks if any classmates of Alex's can help recall the concept he is talking about and then

when no one jumps in, she simply asks if anyone can reiterate Alex's idea. These moves go towards pushing on the students to articulate their thinking more clearly. She hasn't passed any value judgement on the idea at all, it's not even clear how well she understands the idea. But she is working to both understand and push her students to explain the thinking more clearly.

Alex: Historical constraints.

Sharon: I mean, it's basically like the same sort of thing that like Sophia was just talking about with, like, a trait, like a trait that doesn't, like natural selection exists based on like the traits that already exist in a population. And like...so, like if historically, if a trait hasn't existed in a population, then it can't...then like, it's not gonna, like, it's not gonna be selected for if it just doesn't exist.

Alex: Yeah. So, in that panda example, despite like the opposable thumb being like more beneficial, it's not gonna evolve that because it's already, the panda already has its...

Susan: Ok.

Alex: ...thumb.

After turning things over to the class, Susan simply listens while Sharon tries to reiterate Alex's original idea (while also relating it to an idea brought up earlier in lab by another student, Sophia). Sharon's voicing of the idea seems to help Alex refine his thinking and he chimes back in while Susan continues to listen. Alex is then able to articulate his point that even though an opposable thumb would be a 'better' adaptation for a panda to have, it is historically constrained by its existing fingers to have a slightly 'worse' adaptation.

1. The Influence of the BIO14 Curriculum on Susan's Response

The students have now experienced five weeks of the inquiry-based style of lab and perhaps are feeling more comfortable with the structure of the course requiring the articulation of disciplinary ideas. Alex, the initial student in this interaction, clearly is bringing a concept about evolutionary constraints that he heard about in the lecture portion of the class to the lab. Perhaps not fully understanding his first statement, Susan pushes Alex to just 'use his own words' instead of trying to remember a specific textbook definition. We might imagine that earlier in the semester, Alex would have been more timid in the face of Susan's request – we see that disciplinary uncertainty left students in Moments 1 and 2 a bit hesitant to deeply engage. In this

case, however, Alex goes on to explicate his idea about constraints on selection. This willingness to engage is likely to have supported Susan's reciprocal willingness to give Alex space to articulate his thinking.

We also return to the point from Moment 2 about the role of the canonically expected ideas. In the first two moments, Susan's interaction with the students is centered around answering a question about a mutation rate for which there are some general consensus expectations. In this interaction, the discussion revolves around a more open-ended topic (why haven't all traits become maximally beneficial) that may have been perceived by Susan as less bounded by canonical ideas or directions.

2. The Influence of BIO196 on Susan's Response

By the sixth week of BIO196, the TAs had gotten more practice with describing and interpreting student-articulated thinking. Our weekly discussions about video now included conversations about how to respond to student ideas. As the PD instructors, we encouraged the TAs to consider a suite of responses to any particular moment. That is, we wanted the TAs to consider how a variety of moves might impact what happens next after students share ideas in the classroom.

We see Susan making two primary moves in this moment with Alex. First, she pushes him to articulate his idea 'in his own words' when he appears to be struggling with remembering a specifically worded definition from lecture. Second, she turns the idea over to the class and asks if anyone can "reiterate" Alex's thinking. We view both of these moves as being more advanced in their responsiveness, in that not only is Susan engaging with Alex's idea, but she is encouraging elaboration and collaboration on top of that idea. These types of moves – ones aimed at driving more student conversation and elaboration – were often discussed in the PD

sessions. More often, the *concept* of driving these kinds of student follow-ups to ideas was discussed, as opposed to specific moves that could draw them out (at least at this point in the semester). We see evidence in this moment of Susan seizing on an instance of an open-ended topic and trying some moves that appeared to be aimed at drawing out more thinking and collaboration from the class on the initial idea.

3. *The Influence of Susan's Beliefs about Teaching on her Response*

To deepen our understanding of Susan's beliefs about teaching, we present a quotation from her post-semester interview in which Susan was reflecting on her experience teaching BIO14:

So I think maybe for the T.A.s, sometimes it is hard to understand the students because, even if they might think they have fully explained their ideas to you, [the T.A.] still didn't get it because maybe you're obsessed with one idea that [has] come up from yourself. Or maybe you just, you really don't know what is going on. So you just really need to give yourself some time, so that you can really understand, okay, what is going on from that idea?

When coupled with her pre-semester interview quote about wanting to teach in ways that avoid 'constraining' her students' thinking, this quote builds on her initial stance by specifying the need to take the necessary time for understanding student ideas. Susan appears to be working on an approach to instruction that allows students to give voice to their own ideas without fear of being dismissed by a teacher who is 'obsessed with one idea.'

Susan's understanding helps explain her interaction with Alex in this third moment. As with the first two moments, the initial articulation of the idea is not entirely clear. But rather than saying that, or even applying her own initially held thoughts on the subject, Susan makes moves in this moment to give Alex space to say more about his thinking. Beyond that, she also creates an opportunity for other classmates to chime in, which Sharon does in this example.

While the situation of this moment is one that occurs at a point in the BIO14 semester when students may feel more comfortable sharing ideas and at a point in the BIO196 semester when TAs were working on developing responses to student thinking, we also see evidence that Susan is developing an understanding that it takes concerted effort to understand the disciplinary substance behind student-articulated ideas.

4. Responsive Techniques Present in this Moment

The depth of responsiveness that Susan engages in in this moment is different than in the previous two. As before, she is engaging with the idea that a student presents; but this time, the responsive moves she makes have progressed from seeds into more well-developed elements. Specifically, in this moment, we see Susan applying the following advanced responsive techniques (e.g., Bishop, 2021):

- Giving students space to elaborate on their ideas (e.g., “you can use your own words”)
- Eliciting student-student collaboration (e.g., “can anyone, like, reiterate what he just said?”)

With the lack of clear articulation in Alex’s first statement, Susan could have dismissed the idea as not matching her own conceptualization. She could have responded similarly to how she did in moments one and two, by making some effort to give Alex space to say more but ultimately directing him back towards where she envisioned the discussion going. Instead, Susan prompted Alex to elaborate on his thinking in his own words and then followed that up by making the move of asking the class to help re-articulate the idea. Sharon, another student, follows up and gives her explanation of Alex’s idea – an explanation that Alex endorses. This kind of student-student interaction and shared explanation of ideas is a hallmark outcome of responsive teaching (see Ball, 1993; Hammer, 1997; Engle & Conant, 2002; Maskeiwicz & Winters, 2012; Grinath & Southerland, 2019).

iv. *Moment 4: Bean Beetle Model Example*

Towards the end of the semester (week 7), Susan wrote about a moment from the bean beetle lab in which her students were tasked with generating graphical models that represented their predictions for how females would make choices about egg-laying positions. Susan reports on the substance of the idea in her journal and also describes her recall of how she responded in the moment.

After I drew a x- and y-axis on board and asked them to create a line representing the model, [Amy] (she is the most active student in my lab and I'm SO appreciated) offered her suggestion on how to make the line. After I asked them to consider how did lines intercept with x- and y-axis mean, she said: "Line intercepts with y-axis may imply a harsh environmental condition where female maximizes her fitness by laying eggs in spite of resource quality. Line intercepts with x-axis may imply a good condition when female maximizes her fitness by comparing resource quality and doesn't lay eggs until she finds a resource with certain level of quality." Those are not her exact word but what I extract built on my own understanding of her idea, for which I also asked her several questions for further clarification. Her idea based on environmental condition is not raised in prep, and I think it is a valuable point to consider and a reasonable representation to the two lines.

In her journal, Susan notes that she asked Amy "several questions for further clarification" and that Amy's idea was not one that she had heard in prep. We went to the video data to see what actually occurred during this moment between Susan and Amy.

Susan: So what is the basis of the models? What are they testing?

Amy: So the model is trying to come up with a way to justify where the mother would put her eggs given the choice of the small or the large bean. And what it does come down to is if we think of x as the amount of biomass that the bean will need to -- that the beetle will need to survive she's always gonna pick the bean that has, um, at least one free x amount, right. Whether it's the smaller bean that has nothing on it or the larger bean that has only one or nothing on it either. Um, but in the case of they're both occupied it's gonna go for the larger one, perhaps because it has more density overall.

Amy's response here contains depth and took her some time to articulate (she paused a few times to think, and also gestured towards written work at her table that showed the

models). In all, Amy's response took her 24 seconds to articulate. Susan was quiet this whole time, allowing Amy the space to get all of her explanation out on the table.

Susan: Ok. So it's like the available bean's biomass?

Amy: Yeah.

Susan: Ok. So let's go back to the question. That was nice. So... what...so the rules of the behavior of an individual female is what, is that she will choose the bean with the largest biomass? To lay eggs on, right?

Susan verifies her understanding of Amy's idea and also compliments it. Similarly to the mutator example above, Susan makes a move to bring the original question back to the forefront. But her response to Amy here is question-based and gives Amy a chance to connect her thinking to the question – a chance that Amy seizes in her closing response below.

Amy: For, um, in the case where, um, neither bean has an egg on it, it doesn't matter, she's gonna choose the one that definitely has enough biomass for her baby.

1. The Influence of the BIO14 Curriculum on Susan's Response

By week 7 of the semester, the class is delving into their third study system (bean beetles) and are quite used to the inquiry-based approach that the lab curriculum is based in. In this example, Susan asks for and engages with Amy's idea about bean beetle oviposition modeling in a way that at first glance looks similar to her engagement with Alex from Moment Two. Susan asks questions to push Amy to elaborate on her thinking. Interestingly, in both moments, the Susan makes a move to bring the original question back to the forefront of the moment. Unlike Moment Two, which has a strong level of canonical correctness embedded in the question about bacterial mutators, the disciplinary uncertainty that surrounded the mechanism by which bean beetles choose their oviposition sites may have played a part in this moment. Neither Amy nor Susan had a strong commitment to a canonically correct answer because it didn't exist in this

scenario. This open-endedness afforded Amy the chance to articulate a creative idea and afforded Susan the chance to listen to that idea, get clarity on it and ultimately compliment it.

2. The Influence of BIO196 on Susan's Response

By week 7 of the PD, our sessions were focused more on developing responses to student ideas. We spent time after watching video clips, playing out various potential responses and anticipating students' reactions to those responses. Several of Susan's moves in this moment – asking clarifying questions and complimenting Amy's idea – may be evidence of her carrying out the practice of trying moves discussed in the PD. Again, the disciplinary context of this situation allowed for Susan to have some 'play space' for trying out pedagogical moves. What encouraged us about this moment, and what feels connected to the central tenet of our PD (responsive teaching), is that some of the moves Susan felt comfortable trying in this situation were more focused on Amy's idea.

The core principle in the PD that we tried to hammer home for the TAs, was the benefits for students that occur in the classroom when their ideas are held up as the disciplinary substance of the discussions. Susan's moves in this fourth moment reflect her taking up that principle and may reflect her attempts to try to enact it in her lab.

3. The Influence of Susan's Beliefs about Teaching on her Response

To deepen our sense of Susan's developing beliefs about teaching, we turn one more time to her final interview. When asked about what stood out to her from BIO196, she noted that some strategies for teaching stuck out, one of which led to her telling us:

So sometimes I really ask the students several questions to just ask them to clarify their ideas more because I don't want to miss one idea that might be great.

We see in this quote, a justification for why she asked Amy a series of three follow-up questions after Amy gave her articulation of her idea. Not only was Susan committed to giving

her students space to think, but she was also driven by the desire to not miss out on any idea that she could have missed at first. As we look at Susan’s responses in the third and fourth moments presented here, we see clear connections to the context of both the lab curriculum as well as what we were doing in the PD. But we also see ample evidence that Susan’s beliefs about teaching were developing over time. Susan was making moves with intentionality; moves that were intended to help students feel comfortable sharing ideas and that were intended to draw out and allow space for elaboration on those ideas. We also see Susan explicitly valuing students’ ideas as “great” and important.

4. Responsive Techniques Present in this Moment

In this fourth moment, we see Susan again engaging in what we labeled as a ‘seed of responsiveness:’ asking questions. Most of what Susan does in this exchange is to ask questions. We view this approach as more advanced responsiveness because in her questions, Susan indicates that she is working with Amy’s idea and also by questioning, is allowing Amy to elaborate on her idea. Unlike her questions in earlier moments, Susan is driving at giving Amy a chance to explain her idea, not trying to direct Amy to a particular idea. We view these questions as examples of more advanced responsiveness from Susan. We characterize her responsive techniques in this moment as:

- Seeking clarification (e.g., “So it's like the available bean's biomass?”) - Complimenting student thinking (e.g., “that was nice”)

Table 1 below is a collation of all of the moves that we observed across these four moments and whether those moves were reflective of a responsive seed or technique.

Table 1. Moves Susan made in the moments analyzed above.

Description of Move	Responsive Seed or Technique?
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Asking questions (Moments 1, 2, 3, 4)	Responsive Seed
Re-voicing student ideas (Moment 1)	Responsive Seed
Putting in effort to consider student ideas (Moments 1, 3, 4)	Responsive Seed
Giving space for students to re-articulate ideas (Moment 2)	Responsive Seed
Giving students space to elaborate on their ideas (Moments 3, 4)	Responsive Technique
Eliciting student-student collaboration (Moment 3)	Responsive Technique
Seeking clarification (Moment 4)	Responsive Technique
Complimenting student thinking (Moment 4)	Responsive Technique

We will close this paper by providing some discussion about how Susan was able to develop responsive seeds of practice into more developed responsive techniques.

V. Discussion

In looking at the four moments presented here from Susan’s journal and lab, we see clear evidence that Susan was capable noticing student thinking and responding to that thinking in a variety of ways (see Table 1). We propose that Susan was initially able to engage with student thinking in ways that showed seeds of responsiveness: asking questions, re-voicing student language, actively considering ideas and providing students space to re-articulate thinking. Later in the semester, we see Susan making different, more advanced responsive techniques, including: prompting elaboration, encouraging collaboration, seeking clarification and complimenting student ideas.

Throughout our analysis, we have examined these moments, seeds and techniques through the contextual lenses of the BIO14 lab curriculum, the BIO196 PD meetings and Susan's own internal beliefs and motivations about teaching. First, we elaborate on the role of context in Susan's ability to apply different seeds and techniques of responsiveness in different situations. Then, we will suggest how context helped germinate Susan's seeds of responsiveness into more developed responsive techniques. Finally, we will discuss the potential for different kinds of interactions, seeds and techniques among different TAs.

a. The Role of Context

As noted, the curriculum for BIO14 was designed with the specific intent to put students in positions to generate and articulate disciplinary ideas. BIO196 was a professional development that was specifically developed and implemented to help support TAs in their ability to engage with these student-articulated ideas. This broad contextualization gave Susan in-roads to focus in on student thinking as part of her PD journal (see Study One for a more detailed analysis of TA journals), and to attempt moves in lab that were intended to draw out and push on student thinking. That is, we view the context within which Susan was operating during her semester of teaching BIO14 and participating in BIO196 as a major contributor to granting her the opportunity to demonstrate seeds and techniques of responsive teaching.

That said, Susan's orientation towards teaching played an important role in Susan's ability to seize that opportunity. In the first two moments presented above, we see Susan showing signs of *wanting* to encourage her students to elaborate and collaborate on their ideas. She notes, rather explicitly, in her journals that at times she "doesn't know how" to engage with student ideas in ways that would drive this kind of productive activity. Susan appeared to feel a tension in these early moments between wanting to give her students room to think but also

having clear expectations of what should be happening in the lab. As lab became more openended, Susan became more able to engage with student ideas as this tension was alleviated.

This desire Susan expresses in her journals, as well as her interviews, to find ways to teach that allow her students to have agency over their ideas and to have space to build on those ideas is a contextual layer to this case study that cannot be ignored. Susan was granted an opportunity to teach a lab that was designed to elicit student thinking based on the curriculum. She registered for a professional development course that was designed to help her identify and interact with the disciplinary substance of student ideas. But it was her internal beliefs about teaching that we believe helped motivate her to take aspects of her experience in BIO196 and apply them to her active experience in BIO14. Susan's drive to "not miss one [student] idea that might be great," was an attitude that dovetailed with the PD to help responsive seeds in Susan's practice take root and develop into more nuanced responsive techniques.

b. Germinating Seeds into Blossoming Techniques

In looking at the moments presented above, we notice that perhaps the most important activity that Susan engaged in with respect to responsiveness was her ability to make different moves in different moments. Responsive teaching necessarily tasks teachers with engaging with student thinking *in the moment*. That student ideas cannot be fully anticipated is part of what makes responsive teaching a challenging practice. Applying different kinds of engagement to different kinds of situations is an ability to be responsive. The layers of context noted and explicated on above – lab curriculum, PD experience and internal motivators – all combined to make each of the moments described above decidedly and substantively different. Rather than suggest that Susan linearly progressed from seeds to techniques of responsiveness, we propose that the germination of the responsive seeds Susan showed early evidence of was a dynamic process that required Susan to react to context.

For instance, in Moment Three, Alex articulated an idea about historical constraints on natural selection that was linguistically murky at first. This articulation was not thematically unlike what we saw in Moment One when the group of students were initially struggling to voice their idea about UV ray impacts on mutation rates. The moves that Susan made in response to these two student instances of unclear ideas were different! In Moment One, Susan asked questions, tried to co-opt student language and literally told the students “let me think” about their idea. We viewed these moves as productive seeds of responsiveness in comparison to her more overtly responsive moves of encouraging elaboration and generating collaboration in Moment Three. But the argument here is not necessarily that Susan *should* have engaged in more developed responsive techniques in Moment One. In fact, had Susan, for instance, offered up the groups’ idea about UV rays to the class to generate collaboration on the idea, it may very well have taken the class down a non-productive disciplinary road.

Once again, the moves Susan made varied between moments – and often in ways that showed an intersection between her beliefs about teaching and what opportunities she saw present in the lab curriculum. In Moment Three, Alex was articulating an idea that came in the context of an open-ended discussion about evolutionary constraints. The spirit of the moment was driving at generating ideas. Had Susan responded to Alex’s idea with some of the nudging-towards-her-own-understanding that we see in Moment One, it might have shut down the additional thinking we see in the moment when Susan pushed for elaboration and collaboration. In Moment Three, the more developed responsive techniques may have better suited the situation.

What we propose here is that what enabled Susan to take some of her early seeds of responsive teaching and germinate them into more developed techniques was her ability to react to context. Growing with her students over the course of BIO14 likely helped support that

ability, as did her experience in BIO196. Certainly, Susan's internal drive to give her students space to think supported this contextualizing ability as well. The coupling of all of these layers of context that Susan was operating within is what we believe supported her ability to react to different situations with different pedagogical moves.

c. Wondering about Differences among TAs

We close this paper with an acknowledgment that all TAs who taught BIO14 and participated in BIO196 may not have engaged with student ideas in the same ways as Susan. Not all TAs would contextualize moments in the same way, and we would therefore expect a suite of different kinds of engagement across TAs. In addition, student ideas that emerged across lab sections spanned a wide variety of depth and discipline-relatedness. A similar analysis to this one on any or all of the other TAs in our PD would likely yield different nuances in the kinds of seeds and techniques of responsiveness that came out.

Susan had internally held beliefs about teaching that had initial alignment with the concepts of responsive teaching. Certainly, other TAs would have different internal beliefs about teaching (see Julian from Goertzen, Scherr & Elby, 2010). The differences in these beliefs – and their alignment, adjacency or opposition with the principles of responsive teaching would likely have significant impacts on the kinds of moves that different teachers might make in similar moments.

We view the likelihood of these kinds of differences as being very in line with what this case study analysis is suggesting: context matters! Responsive teaching is a challenging practice that demands in-the-moment decisions about how to engage with student ideas. Classroom experience, professional development support and internal beliefs about teaching all can help shape response patterns. The differences in those layers of context for different teachers is what ultimately shapes responsive development. For future work in professional development, and

curriculum design, that is focused on responsive pedagogy, we simply suggest that practitioners take into account the role of context. Considering the likelihood of different internal beliefs about teaching can help PD designers develop more open-ended methods that allow for articulation and incorporation of those varied beliefs. Coupling PD with class curriculums that are intended to encourage student thinking can lead to a sweeping variety of moments that may occur; we believe that engaging teachers in that varied idea-space is a key to developing their skills as contextualizing responsive teachers.

Study 3: Analyzing Interactions from a Responsive Teaching PD to Identify Frames Applied to Student Thinking by Teaching Assistants

I. Introduction

a. Novice Science Instructors: Teaching Assistants

Our study will focus on examining how a relatively understudied population of instructors – graduate student teaching assistants (TAs) – framed moments of student ideas during discourse in a responsive teaching professional development. TAs are typically novice teachers who are working towards becoming disciplinary experts. Teaching assistantships are frequently awarded to Master’s and Doctoral graduate students to fund their early years in school. While colleges may understandably assume a level of content mastery from TAs that qualifies them to teach a course, TAs are often inexperienced or even completely new to teaching. A lack of pedagogical experience can often lead novice teachers to simply teach the way they were taught (Lortie, 1975) and colleges have historically lacked in offering teachingcentric training for TAs (Schussler et al, 2015).

This combination of inexperience and lack of training is likely to lead to introductory science courses being taught in the ‘sage-on-the-stage’ manner, wherein students are positioned as content novices needing to be directly instructed on canonically factual information. Recent education research in STEM fields has suggested that an approach to science instruction that elevates student ideas as part of the substance of the learning experience is more likely to support deeper conceptual understanding and more equitable participation in class (Hammer, 1997; Warren et al, 2001; Engle & Conant, 2002; Rosenberg, Phalen & Hammer, 2006; Hammer, Goldberg & Fargason, 2012; Manz, 2015).

b. Responsive Teaching

In order to elevate student ideas as part of the disciplinary fabric of a science classroom, it becomes necessary for both the curriculum and the instructor to work in tandem to elicit student thinking. Following up that elicitation by focusing instruction on noticing, attending to and responding to the disciplinary substance of student ideas is an approach to pedagogy known as responsive teaching (Robertson, Scherr & Hammer, 2015).

Implementing responsive teaching practices can be challenging for instructors (see Ball, 1993), especially novice or novel instructors like graduate student teaching assistants (Levin & Richards, 2009; Goertzen, Scherr & Elby, 2010; Grinath & Southerland, 2019). Taking class time to unpack and interrogate student-articulated ideas can sometimes feel like it is robbing the instructor of time that should be spent on delivering specific, standardized content-based knowledge to the students (see Ball, 1993). The pressures that instructors can feel to meet curriculum demands (especially novice teachers like TAs) within a designated timeframe can make a responsive approach feel genuinely challenging and can lead instructors to listen to student ideas for specific indicators of correctness rather than disciplinary substance (Goertzen, Scherr & Elby, 2010).

Recent evidence suggests that there is a fundamental difference between student-centered instruction and student-thinking-centered instruction, in that the former can be non-disciplinary focus on things like behavior, while that latter is a focus on the disciplinary substance of student ideas (Gehrtz, Brantner & Andrews, 2022). STEM teachers may differ in their abilities to specifically leverage student thinking in their teaching approach (Gehrtz, Brantner & Andrews, 2022). We designed a professional development for biology teaching assistants that was intended to encourage a focus on *student thinking* specifically. That is, our goal was to encourage our biology TAs to engage responsively with the disciplinary content present in student articulated thinking and ideas.

c. Responsive Teaching Professional Development

Using prior work in PD design, we developed a responsive teaching-focused PD that used classroom video (Sherin & van Es, 2005) as well as reflective teaching journals (Schussler et al, 2008) to help TAs gain exposure to and experience with noticing and responding to student

thinking and ideas. Part of the goal of the PD was to give our group of novice teachers an opportunity to learn about responsive pedagogy in a ‘problems of practice’ atmosphere (a la Mikeska, Anderson & Schwarz, 2009). We wanted to give our TAs a collective, low stakes way to engage with an approach to teaching that may have felt new, scary, and hard with the goal of developing their responsive practices for eventual application in a classroom setting.

In this paper, we analyze data from the PD itself to make sense of how the TAs were engaging with student thinking in this environment. We were curious to see how TAs noticed and discussed student ideas within the context of the PD. To conduct this analysis, we turned to the literature on framing and discourse analysis to better understand how to examine TA talk and tone during the PD.

d. Using Framing as a Theoretical Framework for Characterizing TA Engagement with Student Ideas

Framing can be broadly described as an individual’s sense of “what’s going on here” (MacLachlan & Reid, 1994; Petritis, Kelley & Talanquer, 2020; Tannen, 1993). More specifically, Hammer et al. (2005) describe a frame as a “set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act” (p. 9). Framing analyses have been used to make sense of what students are up to in science classes (Berland & Hammer, 2012; Berland & Reiser, 2011; Elby & Hammer, 2010; Scherr & Hammer, 2009). These studies, show how different learning environments helped students activate different frames as they worked to understand disciplinary concepts.

More recently, Watkins, Jaber & Dini (2020) examined how teachers framed science concepts as they worked through an online responsive teaching professional development. Elementary and middle school teachers who participated in the four-week online PD course gained experience engaging with and ‘doing’ science as a way to experience the kinds of

activities they were supposed to encourage their students to do in the classroom (Watkins, Jaber & Dini, 2020). Richards et al (2020) analyzed STEM teachers practices in the classroom and identified ways teachers were framing classroom activity. They used these frames to develop a deeper understanding of why novice teachers show inconsistency in their abilities to notice and respond to student thinking (Richards et al, 2020). These studies that analyzed frames that teachers were applying to content and students were informative for our approach. We modeled aspects of our framing analysis after the work of Richards et al (2020) as their efforts to use a framing analysis to better understand teachers' ability to be responsive had overlap with our work. Whereas Richards et al (2020) used framing to better understand inconsistencies in teachers' classroom approach, we use framing here to understand what TAs were up to during our PD, specifically with respect to engaging about moments of student thinking.

Our approach to framing analysis will also differ from these studies in that we will specifically analyze framing patterns that our TAs engaged in *during the PD as they watched video of students sharing ideas*. The next step of our approach involved figuring out how to identify the existence of frames our TAs were applying. With that in mind, we turned to the literature on discourse analysis.

e. Using Discourse Analysis as an Approach to Identifying Frames TAs Apply to Student Ideas

Discourse analysis is a research method that examines “language in use” (Brown et al, 1983) or that studies “verbal communication” (Renkema, 2009). Johnstone (2017) takes an even wider view, describing discourse analysis as “an open-ended heuristic” that encourages researchers to “systematically [pay] attention to every possible element of the potential meaning of a stretch of talk or writing.” Johnstone’s definition expands on the earlier conceptualizations

of discourse analysis to include not just spoken or written words, but also non-verbal cues, tone, and other elements of context.

This expansive approach to discourse analysis has been applied in recent work in STEM education. Examining student talk and tone in a physics classroom gave researchers a chance to see evidence of framing (Scherr & Hammer, 2009). Patterns of non-verbal behaviors as well as students' spoken words were categorized into groups of frames that students were applying to different situations and tasks (Scherr & Hammer, 2009). Examining both the transcripts of the words spoken by the TAs in the PD as well as their tone and non-verbal cues in the video itself allow us to more completely understand the nature of discussions that occurred in our PD. Specifically, we examine the talk and tone of the TAs to identify consistent markers that indicate frames TAs are applying to moments of student thinking discussed in the PD. Our discursive focus of this analysis will help us to get a better understanding of 'what the TAs were up to' when they were discussing moments of student thinking in a responsive teaching professional development context.

We analyzed two specific moments from the PD, one towards the beginning and one towards the end, chosen to help exemplify differences in TA talk and tone that occurred in the PD. By examining these moments for markers of TA speech and behavior, we suggest frames that we believe the TAs are applying to these moments as evidence of the types of ways they engaged with student thinking and ideas. We then present evidence in an appendix that starts to get at the consistency and persistence of the frames we identify in this study. Our goal is to address the question: How are TAs framing discussions of student ideas during a responsive teaching PD?

II. Methods

a. Participants

Our PD course had a total of nine TA participants. All were graduate or undergraduate biological science teaching assistants at a medium-sized private university in the Northeast. Five of the participants were graduate students (Master's or Ph.D. candidates) whose teaching assistantship was awarded as part of their acceptance to the graduate school. The other four participants were undergraduate students who interviewed for paid work study positions as teaching assistants. This study will focus exclusively on the five graduate student TAs who participated in the PD.

b. TA Teaching Assignment: BIO14 Laboratory

Concurrently with our PD, the TAs were teaching sections of an introductory biology lab called BIO14: Organisms and Population Biology. The BIO14 lab curriculum consisted of three model study systems: *Escherichia Coli*, *Mimosa pudica* (sensitive plant), and *Callosobruchus maculatus* (bean beetle). Each model study system was investigated over a three-week period in which the students designed and conducted experiments about the organism, worked with a computer simulation about the organism and then synthesized and analyzed results from the experiments and simulations. Each study system was oriented around an ecological trade-off question:

1. *E. coli*: Is it better to mutate a lot or a little?
2. *M. pudica*: Is it better to forage (photosynthesize) or hide (fold up leaves)?
3. *C. maculatus*: Is it better to lay a lot of eggs indiscriminately, or fewer eggs more choosily?

The TAs were required to attend a weekly prep session before teaching their lab sections. The prep sessions were intended to give the TAs the chance to troubleshoot lab protocols and get a sense for what kinds of student ideas might come up. Teaching this style of inquiry-based lab

inevitably led to moments in which the TAs encountered student ideas and questions that were not previously anticipated or prepared for. These kinds of moments left the TAs in position to make in-the-moment decisions about how to respond, decisions that were undoubtedly influenced by the substance of what they noticed in student articulations. The overarching goal of our responsive teaching PD was to give TAs practice at first noticing the scientific substance (and potential merit) of student thinking and then responding to it in ways that pushed on that thinking. Prior PD work has indicated that providing space to practice pedagogical moves increases teachers' abilities to implement those moves during live instruction (Kazemi & Franke, 2004; Levin & Richards, 2010).

c. BIO196: Student-Centered Pedagogy in Biology

Math education reform has found success with the use of video clubs (e.g., Sherin & van Es, 2005) in the sense that having teachers watch video of classroom moments helped them gain experience and practice at noticing student ideas and thinking. We wanted to implement a similar strategy in our PD for biology TAs. Specifically, we wanted our PD to revolve around watching and discussing video from the TAs' labs themselves in an effort to give them practice at noticing and responding to student ideas and thinking.

Our PD course met once per week for 75 minutes in a classroom familiar to all of the TAs. The course met on Monday mornings, prior to the weekly BIO14 lab section schedule. Given that the lab prep sessions were on Fridays, the TAs in our PD always had both prep and PD prior to their teaching assignment each week.

Concurrently with the PD course, our TAs were teaching sections of the BIO14 laboratory course explicated on above. As part of the PD, we asked the TAs to video record parts of their labs to bring in for discussion in PD. Specifically, we assigned each TA two times during the semester to bring in a short (3-5 minute) video clip from their lab. We instructed the

TAs to bring in clips of moments that they found “interesting” or that “stood out” to them. Our PD sessions were then mostly taken up by viewing and discussing these video clips. We (the PD instructors, also the authors of this paper) tried to direct the flow of the discussion towards two main goals: 1) identifying and making sense of student ideas and 2) developing a suite of potential ways to respond to those ideas. We observed the TAs engaging in these discussions in various ways. At times, the TAs were overtly focused on science content; at other times, they were clearly more invested in parsing out the substance of student ideas. There were also a myriad of more subtle things that the TAs were up to in the course of our discussions. This paper will use a discourse analysis approach to investigate the talk and tone of the TAs during PD discussions in an effort to characterize the kinds of activities they were engaging in when watching moments of student thinking and ideas.

d. Data Collection

We video recorded each 75-minute meeting of the professional development course (with consent from all participants). The room was set up like a conference room such that single camera was able to capture video and audio of all TAs and instructors. These video recordings were downloaded to a password-protected hard drive immediately following each session and then deleted from the recording device.

e. Framing and Discourse Analyses

Our primary goal for this study was to use some moments from the PD to make sense of what the TAs were up to with their interpretations and responses to moments of student thinking. That is, we wanted to identify some talk and tone markers that indicated frames through which the TAs were making sense of student ideas. We analyzed moments from the PD video data to examine how the TAs were taking up (or not) responsive pedagogical approaches. We selected moments from the PD for analysis in which TAs were interrogative of student ideas in

video. Rather than focusing on instances when TAs were describing moments, successes or challenges from their own classes (which happened frequently, and could absolutely be the focus of a future study!), we selected moments for this analysis in which TAs were actively engaging with student ideas that they had just watched in video clips.

We selected two specific moments from our PD that met the criteria above and that clearly illustrated distinctly different frames being applied by the TAs. Our goal in this study was to identify some frames TAs applied to moments of student thinking and to consider how those frames connected to our responsive teaching PD. As such, we found it more useful to choose particularly illustrative moments than to detail an exhaustive list. In order to begin to look at the stability of the frames we present in these moments, we will present some preliminary quantitative data in the form of frame-instance counts from a bounded portion of the full video data set in an appendix at the end of this paper.

The specific details and context of each of the two moments we examine in detail in this paper will be described later, here we aim to explain our approach to discourse analysis. Our analytical approach was largely informed by Scherr & Hammer's (2009) work in studying student behavior as it linked to epistemological framing in a physics class. While our study focus (teachers) and content matter (biology) were different from Scherr & Hammer's (2009) (they were focused on students in a physics class), the approach with which they looked for and categorized talk and tone was very informative for our methodology. Scherr & Hammer (2009) identified what they called "clustered co-occurring student behaviors" as evidence of different ways students were framing what they were up to in class. Scherr & Hammer's (2009) work inspired us to look beyond just the words in the transcript of the moments that we selected. Focusing on talk, tone *and* behavior of our TAs during the two moments we selected gave us a much more holistic view and understanding of how they were engaging in thinking about and

reacting to student ideas. At times, our analysis also led us to look at non-verbal cues that were indicative of the ways TAs were interacting with each other during these discussions. We will use the discursive evidence to identify frames that the TAs appear to be applying to the moments of student thinking under discussion. Ultimately, we will try to connect these frames to the principles of responsive teaching that we were exposing the TAs to in our PD.

III. Results

First, we will provide details of a discourse analysis of two moments from the responsive teaching professional development. Moment One comes from the first week of the PD and TAs are discussing a video clip that involves students discussing bacteria with variable mutation rates. Moment Two comes from the seventh week of the PD and TAs are discussing video clip that involves students discussing rationales for bean beetle oviposition preferences. We will present excerpts of transcript data from each PD discussion. Following the transcript of the episode, we will provide a discursive analysis of the talk and tone that the TAs exhibited in each moment. Using this analysis, we will propose frames that we see the TAs applying to these instances of student ideas. Finally, we will connect the frames that TAs applied to student thinking to the principles of responsive teaching that were at the center of our PD.

a. Analyzing Discourse of Particular Moments from the PD

i. Moment One – Bacterial Growth

The following moment comes from the first week of the PD. Since TAs had not yet taught their first week of labs, the video clips used in the session came from the previous year's lab. The video used for this moment came from the Week One lab that was taught by one of the PD instructors. The video being discussed did not include any footage of the instructor, but rather showed students in discussion with each other. In this episode, a group of BIO14 students

were trying to explain the potential for differential *E. coli* growth on petri dishes that contained glucose only and glucose plus lactose. One of the students in the group, Damian, says the following:

I feel like you can have a higher number of the lactose ones surviving because they won't be competing for the glucose on the plate, 'cause they can just use the lactose that nobody else is using.

Damian appears to be suggesting that *E. coli* that can digest lactose would survive in higher proportions because they would be able to avoid competition for glucose. This idea about competition is the disciplinary substance of Damien's idea because it includes a claim about the differential fitness of the two strains. What Damien says about the "plate" is technically inaccurate. While the bacteria are plated on petri dishes to allow colonization that becomes visible to the naked eye, the actual competition for resources between bacterial cells is occurring *prior to* plating in incubated centrifuge tubes containing the glucose and lactose sugars. From his utterance above, and the group's thinking in the clip as a whole, it is not entirely clear how the students are thinking about where competition is happening.

Damian does say: "...they won't be competing for lactose on the plate..." but it was not clear if he meant that the competition occurs on the plate, or if he meant the visualization of the prior competition (in the tube) would be seen on the plate.

The video clip was paused after Damian's line above and the ensuing TA discussion occurred (*italics* represent vocalized emphasis, gestures and body position are included in parentheses):

Sadie: I think that they're talking about competition happening on *the plate*, which it's not.

Jake: I think *they* might think that most of the competition would be happening on the plate because of the question Damian has with the glucose and whether or not that would ever prove to cause competition.

Ella: Yeah (nodding). That's true (nodding). That seems to be what they're missing.

In describing how the TAs in this excerpt are framing discussing student thinking, we observed three kinds of talk and behavior:

1. Consideration of Student Idea

Both Sadie and Jake start their utterances by clearly indicating an attempt to describe Damian's idea ("I think that they're talking about..." "I think they might think..."). Both TAs give agency over the idea to the group of students through use of the pronoun "they," something that Ella follows suit on with her comment at the end of the episode. The only part of the video clip that is being discussed in this moment is Damien's idea; that is, in this moment, the TAs are fully focused on the substance of the student idea.

2. Focus on the Flaw in the Idea

Immediately after indicating some consideration of the student idea on the table, both Jake and Sadie focused on the flaw they perceived in the students' idea, though in different ways. Sadie applies a correction by succinctly stating that competition is "not" happening on the plate. Jake's consideration of the flaw in the students' idea looks a bit different. First, after Sadie's comment, Jake nods in agreement and then presents his statement as a follow up to Sadie's. He then emphasizes the word "they" in his statement: "I think *they* might think..." This emphasis appears to be used to indicate that Damian is articulating a group idea that conflicts with the correct idea (which has been proposed by Sadie).

3. Tone of Finality

This short exchange ends with Ella stating: "That seems to be what they're missing." This statement is an agreement with Jake's follow up to Sadie's notion that the students are not

understanding that competition does not happen on the plate. The tone with which Ella makes this statement is one that carries decisiveness and finality. The confirmatory nods that Ella gives as she says “Yeah, that’s true,” are indicative of Ella building up to a declaratory statement. As she says her final utterance, she does not intone a question or any uncertainty. Rather, her tone is firm and final, leaving no invitation for alternative interpretations. And in fact, following Ella’s words here, the group moved on to discussing the specifics of the types and quantities of sugars present in the different growth media for the experiment.

ii. Moment Two – Oviposition Strategy

Six weeks after the episode above, the TAs engaged in a discussion about an idea that a student articulated about female bean beetle oviposition preference. Jaime, a BIO14 student in a video clip was part of a group trying to explain why female bean beetles might be more likely to lay eggs on one bean than another:

Maybe females lay eggs on beans that they think have a lower probability of being laid on by a female that comes by after them.

Jaime’s group was grappling with understanding data that indicated that bean beetles often chose to lay eggs on beans that were suboptimal relative to other beans (bean quality was often determined by type, mass, and existence of eggs laid by other beetles). Jaime appears to be suggesting that perhaps female bean beetles intentionally select beans of poorer quality to lay their eggs on in the hopes of avoiding competition from later-arriving females.

The following four-TA exchange occurred after the video was paused after Jaime’s idea. Upon pausing the video, the PD instructor prompted the TAs by saying: “Any thoughts?”

Ella: (looking upwards, as if thoughtfully) I think I would ask Jaime to say more about what she means.

Sadie: (nodding) Yeah I want her to talk more about what she thinks the female would do to assess probability.

Susan: I wonder if she thinks females have some way of protecting their eggs...(trails off)

Jake: I wonder if there's a way this student can explain her theory of female behavior in terms of the *data* we showed them (tone rising at the end of the sentence).

Ella: So maybe the thing to do is ask them to find a way to test their theory (looking around the room at the TAs, as if seeking agreement).

While there is some thematic overlap with this moment and the prior one, some of the categories from the first episode (correction of student thinking, tone of finality) do not exist in this dialogue. Instead, we see the following categories of talk and action:

1. Consideration of Student Idea

As in the first episode, there is ample evidence here that TAs are considering the idea that Jaime presents. All four TAs ascribe the idea on the table to Jaime specifically, Jake even explicitly describes the idea as “her theory.” The content under discussion in this episode is the substance of Jaime’s idea, and as with Moment One, the TAs grant agency over the idea to the student herself.

2. Focus on the Disciplinary Substance of the Idea

One of the new phenomena that occurs in this clip relative to the first one is the TAs working hard to understand the student idea on the table. The TAs want to know more about the idea! Ella starts the episode off by saying she wants Jaime to “say more about what she means.” This opening comment sparked a dialogue among the TAs that centered on unpacking Jaime’s idea. Sadie wondered about ‘probability assessment’ mechanisms that Jaime might be thinking about, Susan openly wondered about whether Jaime was thinking about ‘egg protection,’ while Jake was interested in how Jaime might explain her theory relative to existing data. This

engagement with the substance of the student's idea also came with a dramatically different tone than was present in the first episode:

3. *Tone of Curiosity*

Both Susan and Jake begin their statements with "I wonder..." Ella finishes the conversation with an idea for how to engage in the moment with this student by saying, "So maybe the thing to do is..." Throughout the exchange, the TAs are exhibiting words and behaviors that indicate they are curious about Jaime's idea and want to hear "more." This is in contrast to the first episode which included statements of correction and a tone of finality. In this dialogue, Ella accompanies her comment with a thoughtful, curious upward gaze. Jake voices his idea with the classic tone of rising-at-the-end-of-the-sentence associated with uncertainty and curiousness. The phrase "I wonder" explicitly communicates a curiosity and uncertainty about what and how the student might be thinking. This tonal difference from the first episode also drove a greater diversity of possible interpretations from the TAs. In the first episode, the three TAs generated and agreed on a single interpretation of Damian's idea. Here, each TA offers a different line of thinking about Jaime's idea with Ella concluding by offering a suggestion for how to engage with it live in the moment.

b. Using Discourse Patterns to Identify Frames

i. Frame 1: Diagnosing a Problem

The three thematic elements present in Moment One above – consideration of student idea, focus on the flaw in the idea and tone of finality – lead us to consider what the TAs were up to collectively in the moment. Thinking about the idea at hand, focusing on the canonical flaw in that idea and then feeling satisfied with identifying that flaw is a very diagnostic approach to discussing a student idea. Sadie, Ella and Jake were framing this episode as an opportunity to *diagnose a problem with student thinking*. Sadie and Jake were working to identify the flaw in

the students' thinking and Ella's agreement suggested that she too saw the as central to the discussion. Together, the TAs were engaged in diagnosing a problem. We note here that there was not ensuing discussion around resolving the problem, but rather expressing satisfaction (mostly by Ella) about having effectively diagnosed it.

ii. Frames 2 & 3: Investigating Student Thinking & Proposing Moves

The three markers we observed in Moment Two: considering the student idea, focusing on the substance of that idea and doing so with a tone of curiosity pointed towards the TAs being engaged in a different framings. Specifically, we see evidence of two overlapping frames.

The first, investigating student thinking is exemplified by Susan's utterance: "I wonder if she thinks females have some way of protecting their eggs...(trails off)." With this line, Susan is not considering how to draw out more thinking or proposing any pedagogical moves to make. She also is not being diagnostic with respect to a noticed flaw in student thinking. Rather, Susan is trying to dig deeper into the idea the student has proposed by offering a potential explanation for the idea. Susan uses the "I wonder" language of curiosity that we noted above (her trailing off also seems indicative of her thinking aloud), but rather than curiously propose a potential move to make, Susan is *investigating the thinking behind the student's idea*. We see evidence from Ella, Sadie and Jake they are also wondering about the meaning of Jaime's ideas.

These three TAs also exhibit evidence support a second, overlapping frame of *proposing moves*. Ella, Sadie and Jake displaying these markers as they try to think moves an instructor could make in the moment to elicit more from the student or to suggest that the student engage with data or propose a test of her idea. The TAs in this episode are using that focus as well as a curious tone, to consider and propose moves that they would make to draw out more thinking or elaboration on Jamie's idea.

Next, we consider these frames within the broader context of responsive teaching in an effort to connect them to the principles of that approach to pedagogy. We also make recommendations for using a similar analytical approach for future studies centered on professional development.

IV. Discussion

We see evidence from these episodes that TAs engaged in different kinds of framings when watching video clips of students articulating thinking and ideas. We saw the TAs at times frame these moments as times to ‘diagnose problems’ with student thinking. We also saw evidence of TAs framing student ideas as moments around which to further ‘investigate student thinking.’ Perhaps most interestingly in terms of its connection to responsive teaching, we saw evidence in the second moment of TAs framing a student idea as a moment around which to ‘propose moves’ with respect to pedagogy.

Each of these framings is substantively different and evidentiary of TAs ‘being up to’ different kinds of tasks. Here, we discuss the relevance of the variation in frames we observed in these moments by postulating about what layers of context may have pushed the TAs into one frame or another. We call back to the explanation of a frame provided by Hammer et al (2005) as being a “set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks to act.” With that description in mind, we try to explain what may have influenced the frames the TAs applied to these moments.

Our preface at the beginning of this first PD session included some explanation of how we wanted to use the video clips as a way to help hone the TAs’ collective noticing skills. One of the TA instructors described it this way:

It's kind of analogous to like, you know, natural history, right? You're going into this, the jungle of the classroom and you're trying to learn what to pay attention to and how to notice differently. That's the kind of skill that we're trying to cultivate as teachers. Part of

the skill of being a teacher is just learning to notice differently from how you've noticed other times. That's what we're practicing in depth with these clips.

What we will suggest here is that the TAs in fact showed evidence of being able to “notice differently.”

A. What Influenced TAs to Mostly Apply a 'Diagnosing a Problem' Frame in Moment One?

Moment One occurred during the first week of the PD. The TAs had not yet taught the first week of their labs and we therefore used video recordings from previous years of the lab for the substance of the conversations. The moment that made up this moment included a student, Damien, who may or may not have been articulating a misunderstanding about when competition occurred during the course of the *E. coli* experiment. This potential misunderstanding is what attracted the TAs' attention about the idea and the ensuing discussion among Sadie, Jake and Ella is focused on solidifying an articulation of that misunderstanding.

We suspect that in this early stage of the PD, the TAs were focusing on what was comfortable to them: their understanding of the science. The TAs understood that in the *E. coli* experiment, competition happened when the different bacterial strains were grown together in plastic tubes – the plating process was just a mechanism for visualizing which bacteria survived the competition. Damien's utterance leaves open the possibility that he thinks the competition itself is happening on the plate. This potential mismatch is an element of the thinking that the TAs can easily seize upon and talk about. Diagnosing the problem with Damien's thinking was a comfortable framing space for the TAs to be operating within.

The TAs may have felt less comfortable with framing Damien's thinking as an opportunity to 'identify productive seeds.' We can look at Damien's idea and see that there are productive disciplinary seeds of understanding there. He understands that bacteria that can digest lactose would be at an advantage in over other bacteria in conditions that have lactose

present. Even besides that, Damien clearly sees this experiment as one that is testing the effects of competition. These are productive, disciplinary components of Damien's thinking that none of the TAs in this moment mention. It is harder to point out productive thinking in an idea that can be diagnosed as wrong. It may leave a TA open to disagreement or even dismissal from other topical experts (the other TAs in this case). As content experts but teaching novices, it stands to reason that TAs would feel more comfortable focusing on scientific correctness rather than potential merit in student ideas. The 'identifying productive seeds' frame could also have been challenging for these novice responsive teachers to apply simply because they had not had much practice at this task.

It takes practice and intentionality on the part of instructors to not simply judge disciplinary ideas based on their level of canonical correctness (Ball, 1993; Coffey, Levin, Hammer & Grant, 2011; Hammer, 1997; Hammer, Goldberg & Fargason, 2012; Rosenberg, Phelan & Hammer, 2006). We suspect that our TAs lacked that practice during week one of the semester and thus we did not find it surprising that they engaged in a more diagnostic framing of Damien's idea.

B. What Influenced TAs to Mostly Apply a 'Proposing Moves' Frame in Moment Two?

In Moment Two above, we saw several of the TAs apply a decidedly different frame to Jaime's idea about bean beetle oviposition. After hearing Jaime's idea, Ella, Sadie and Jake all were up to something different than 'diagnosing a problem' – rather, they each were engaged in considering or proposing moves that could be made in the moment to draw out more thinking from the student.

Needless to say, this frame is more in line with a classic understanding of responsive teaching. Now in the seventh week of the PD, we had spent ample time as PD instructors encouraging the TAs to listen for student thinking and then approach that thinking in ways that

might help encourage elaboration. It certainly doesn't surprise us that the TAs were more able to engage in this kind of framing and activity in week 7 of the PD than they were in week 1.

What we find fascinating about this moment is the general similarities that exist between the student ideas that triggered these very different frames. Both Damien and Jaime communicate their ideas with some uncertainty in their tones of voice. Furthermore, it seems conceivable that TAs could key in on potential misunderstandings in both ideas. The 'flaw' in Damien's thinking was quickly identified and diagnosed by the TAs in Moment One. In Moment Two, Jaime could be interpreted as saying that female bean beetles will *intentionally* choose beans of poor quality on which to lay their eggs so as to discourage future females from using the same bean. The TAs could have focused on this idea as an unlikely explanation for the data. It is not hard for us to imagine a TA conversation about Jaime's idea that would look similar to the one they had about Damien's idea. Wondering about the validity of Jaime's idea, pointing out that her claim is at odds with the accepted understanding of what beetles do, and diagnosing the situation as Jaime having 'missed' something is a path the TAs could have taken.

Instead, Sadie, Ella and Jake express ideas about how they'd like to hear Jaime elaborate on her thinking as well as some moves that a teacher could make to help support and draw out that thinking. One interpretation of this shift in framing could be attributed to the flavor of the moment. Damien's idea was about a very concrete element of the lab: the experimental set up. Jaime's idea was about a much more open-ended component of the lab: an interpretation of data. Jaime's idea being about something that had a less known 'correct' answer may have supported the TAs in being more curious about her thinking. In addition to this lab curriculum element, we also believe that the work the TAs did over six plus weeks in the PD leading up to this moment helped them be able to apply this different frame. The practice that the TAs got in the PD at making sense of and interpreting student thinking in video helped them be able to hear an idea

that could have been interpreted as a misunderstanding, and put in concerted effort to think about the substance of the idea itself (instead of focusing on a potential flaw).

We will show preliminary data in Appendix A of a frame stability analysis that indicates early evidence of some of the TAs applying these more responsive frames even during week 1 (see Table 1, Appendix A). The example in Appendix A, Table 1 “I think inducing hesitation is productive” is an example of one of the TAs, Jake, commenting about the benefits of a theoretical move of giving students pause. This comment begins to enter the ‘proposing moves’ frame though it is less developed than what we see in Moment Two of the above analysis as Jake was proposing a concrete move to make in a specific moment. We were encouraged to see that TAs were up to more than simply diagnosing problems, even early in the semester, and we were interested to see that the frame of proposing moves roughly appeared even as TAs were at the beginning of the responsive teaching PD.

In week 7, Ella is framing Jaime’s idea as a moment to propose concrete, actionable moves: “So maybe the thing to do is ask them to find a way to test their theory.” This progression feels very connected to the work we did in the PD. As the semester progressed, we moved our discussions in the PD from simply noticing the presence and substance of student ideas to developing suites of moves to make if we were the instructor in the moments. We see evidence with this moment in week 7 that the TAs took up some of the elements of these discussions and became able to frame the moments in video as opportunities to put those elements into practice.

While the two student ideas present in the two moments presented here had similarities (both were single students voicing ideas about potential data, both were grounded in the disciplinary concept of competition, and both occurred early on in the investigation of a new study system), it does not escape our attention that the kind of moment could be a layer of

context that would also impact TA framing. That is, in a different type of moment when students may have been interpreting data from their own studies or providing details on the design of their own experiments, it's conceivable (and even likely) that different frames would emerge during the TA discussions. We focus our interpretation of the moments above to suggest that TAs were capable of multiple frames when it came to student ideas, and here we connect those frames to their experience in our PD. However, there are certainly multiple contextual elements that impacted the TAs understanding of what they were up to in each moment. Damien's idea was much more bounded by obvious standard biological knowledge, while Jaime's was much more flexible in its interpretation of data that did not have a known correct explanation. What we find interesting is that the TAs were able to apply different frames in different moments, and in the later moment, after longer participating in our PD, the frames being applied were more responsive and focused on the substance of the student idea.

C. What Influenced Susan to Apply an 'Investigate Student Thinking' Frame in Moment Two?

A common theme in all three studies in this dissertation has been that Susan is a TA who stands apart from the rest of the group. In Study One, we note that Susan's journal entries were more introspective and considering of alternative moves than any other TA. In Study Two, we do a deep dive into Susan as a case study, and we consider how various layers of context influenced how she engaged with student thinking in her live teaching labs. Here, we see some evidence that even within the context of the PD, Susan is engaged in something slightly different from her peers. Using Hammer et al's (2005) conceptualization of a frame, we see evidence that

Susan was consistently using one of her self-stated guiding principles to generate her expectations relative to a moment. Susan was driven by the goal of not constraining her students' thinking (see Study Two). The frame she applies in Moment Two above, of 'investigating student thinking' is very in line with that self-motivated goal. Rather than diagnose problems, or even consider moves, Susan simply wondered aloud about further depth to Jaime's idea.

Susan's commitment to fore-fronting student thinking is a common thread we see through her journals, her in-class actions and now her engagement in the PD. This theme leads us to heavily consider the influence of personal beliefs about teaching on how TAs take up responsive practices. Case study analysis of the other TAs in this PD has not yet been conducted, but we would anticipate that differences in the ways that Jake, Sadie, Ella and Charlie took up responsive teaching in their journals, classrooms and PD interactions would be similarly influenced by their personal beliefs about teaching as they were for Susan. Future studies should consider these differences in beliefs, considering interview as a data-based way to get at an understanding of the nature of those differences.

D. Investigating Overlaps between the Three Frames

Our analysis also suggests overlap among the three frames identified (see Figure 1). In both moments presented, the TAs are all attending to student ideas. That is, we see clear evidence in all three frames, that the TAs are focusing their thinking on the substance of student ideas; Gehrtz, Brantner & Andrews (2022) note this kind of discourse as student-thinkingcentric. We suggest here that attending to the thinking that Damien and Jamie were engaged in in these two moments allowed the TAs to enter into the frames of diagnosing problems, proposing moves and investigating thinking. Each of these three frames necessarily requires that the TAs were focused on the substance of student ideas; we view the frames we identified as some evidence of

how the TAs were leveraging those ideas. The consistent attention to student thinking exhibited by our TAs is notable, given that such a focus seems to be relatively rare among science faculty (Gehertz, Brantner & Andrews 2022).

Furthermore, we note that the frames we identified in this study are not mutually exclusive. That is, elements of each frame could be present simultaneously, indicating that the TAs could have been up to multiple things at the same time. For example, a TA could apply a diagnostic frame to a student idea while also proposing moves to make in the moment. This combined focus could ultimately lead to a comment that diagnoses a problem with the idea and proposes a move to make. Consider Ella's final comment in Moment One: "That seems to be what they're missing." We identified the focus on the flaw and the tone of finality here as markers of Ella engaging in the 'diagnosing a problem' frame. Suppose that Ella had continued this line of thought in this way: "That seems to be what they're missing. I wonder if you could ask them when they think competition is happening during this experiment." This addendum would shift our analysis of this moment to include the focus on substance and tone of curiosity that we see present in the 'proposing moves' frame.

Our point here is that we do not view our identified frames as exclusionary windows through which TAs view student thinking. Rather, these frames are more like lenses that can be raised, lowered or even combined as TAs engage in discussion about student ideas. Each lens has its own degree of responsiveness – proposing moves required the TAs to notice, attend and theoretically respond to student ideas, investigating student thinking required noticing and attention paid to the idea, and diagnosing the problem really only required noticing the presence of the idea. By focusing our PD on responsive pedagogical practices, we believe we helped support our TAs in entering into these frames from a starting point of noticing student thinking.

In this study, we identify three frames that we observed TAs apply to moments of student thinking in a video-based professional development. Here, we add on to that identification of frames by claiming that the frames may overlap or even be simultaneously applied from moment to moment. In Figure 1 below, we show a visual for how these frames overlap with the construct of responsive teaching as well as with each other.

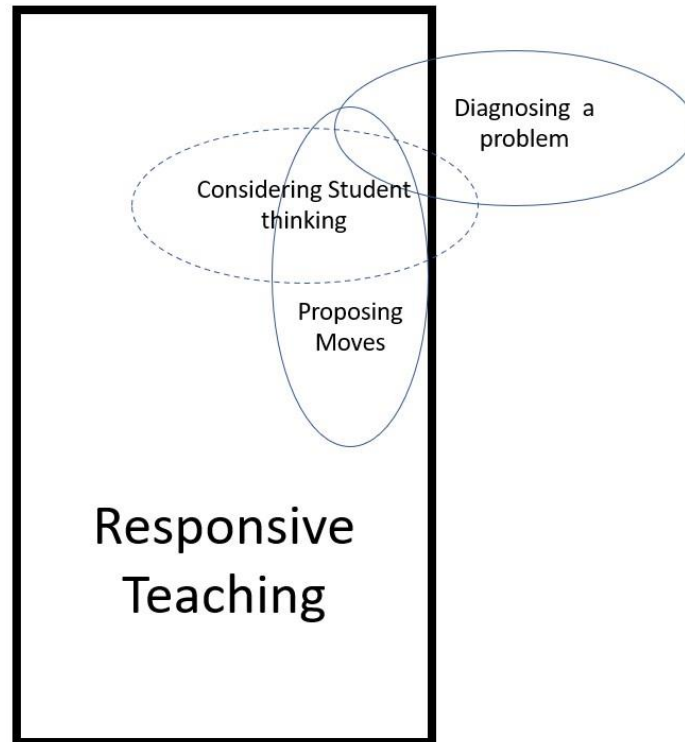


Figure 1. Illustration of how frames overlap with each other and the construct of responsive teaching. Points of frame overlap indicate times where markers of speech could be simultaneously indicating multiple frames.

One final note about Figure 1 that does not escape our attention: all of the remaining ‘unframed’ space within the responsive teaching window. Our suggestion here is that there are many other ways of framing student ideas that would map on to responsive teaching practices. A more exhaustive framing analysis of the entire PD semester might reveal some of these other responsive framings.

E. Conclusions and Implications

We close this paper by suggesting a final contribution of our study design as being a tool for future use in analyzing PD interactions. Frames are a useful tool for understanding what teachers are up to in their interactions during a professional development. To be able to characterize these frames, we found it useful to take a discourse analysis approach to some small moments of discussion from the PD meeting sessions. In continuing this work, we intend to conduct a more thorough analysis of moments from each week of the PD to be able to better make claims about shifts over time in how the TAs framed moments of student thinking (see Appendix A for some preliminary data in this vein).

For other work, we suggest this approach as a way of first identifying frames that PD participants apply. Those frames can then be used to make claims about how those participants took up elements of the PD they took part in. As a tool for understanding PD impact, we think this analytical approach of using discourse analysis to identify frames can be very useful. We also see utility of the approach for characterizing differences among different participants (as with Susan in this case). Professional development impact can be difficult to measure, both because of the exhaustive amount of data that can be required if collecting in-class data and also because of personal differences in motivation among participants. We believe that our approach here is an effective way to use data from the PD itself to investigate uptake by the participants; and we suggest that accounting for individual differences can make for a powerful understanding of the impacts of context on PD outcomes.

V. Appendix A

Here we present a preliminary quantitative indicator of the stability of the frames we observed in the discourse analysis. In order to develop this dataset, we examined the entirety of the first PD course meeting (the meeting that contained Moment One) and located the times that

each of the three frames we identified above were applied by TAs during the discussions around moments of student thinking. We present preliminary data that shows the consistency and persistence of frames that TAs applied during these discussions.

The first PD session lasted for 75 minutes. During that time, the TAs spent approximately 35 minutes actively discussing student ideas that they watched in a video clip. The remaining time was taken up with actual playing of the video clip itself along with some logistical discussion about how to engage with the content in the PD. Additionally, some of the meeting time was taken up by the instructors of the PD providing context of the moment displayed in the video.

Across the TA discussions, we saw evidence of TAs applying a diagnostic frame to student thinking fifteen times. These instances of framing included the markers we note above (considering an idea, focusing on the flaw, and feeling satisfied with identifying the flaw as evidenced by a tone of finality). There were numerous other times during discussion when some of these markers were present. For instance, there were several times when TAs proposed interpretations of student ideas as being problematic, but rather than appear tonally satisfied by this interpretation, they would ask if anyone shared their thinking. In one moment, Ella proposes her interpretation of a student proposing an experiment that she thinks is asking a fundamentally flawed question. After her interpretation of the idea, she asks the room, “Does that make sense?” We view this framing as subtly different from the diagnostic frame we explicated on above. Ella considered the idea, focused on a flaw (the first two markers of our diagnostic frame), but then used a tone of uncertainty rather than of finality. Rather than satisfactorily diagnosing the problem in this instance, Ella used a different framing that we might call *seeking validation of interpretation*.

As anticipated, the ‘proposing moves’ frame was used less frequently in the first PD session. We saw evidence of this frame being applied by TAs two times. These instances included the three markers noted above: considering student thinking, focusing on the substance of that thinking, and doing so with a tone of curiosity. To be clear, the TAs considered the substance of student ideas with great frequency. Many times in discussion, even in the first week, TAs engaged in consideration of the substance of student thinking without focusing on flaws. But often times, this conversation was perfunctory in nature and ended without consideration of teacher moves.

In many of these cases, the TAs were more disciplinarily-theoretical in their conversation, a brand of curiosity more similar to Susan’s in the ‘investigating student thinking’ frame. We saw evidence of this frame 9 times in the first week of the PD. For example, Jake spent time explicating on his belief that the students were developing a mental model for how mutation works. He didn’t necessarily indicate flaws he perceived in that model; nor did he suggest what he would do if he was in the room with the students. He was simply focusing on the substance of the idea the students were talking about.

Table 1. Frequency of the three identified frames during week one of the PD.

Frame	Number of Occurrences	Example
Diagnosing a Problem	15	“I think at this point they didn't know about this culturing as a different thing than the plating.”
Proposing Moves	2	“I think inducing hesitation is productive.”
Investigating Student Thinking	9	“I think Damien is trying to create some sort of conceptual model before actually applying the knowledge that he already has.”

In light of this preliminary data, we suggest that the markers we used to denote the frames described above were stable, even early in the PD. TAs frequently and consistently considered student thinking and focused on flaws or the substance of those ideas. We also saw repeated (though less frequent) evidence of the TAs discussing those flaws with a tone of satisfaction and discussing ideas substance with a tone of curiosity, markers that contributed to our frames of ‘diagnosing a problem,’ ‘proposing moves’ and ‘investigating student thinking.’ We suggest that these three ways of framing discussions about student ideas may have stably applied by the TAs.

Further in-depth analysis of the PD sessions will be required to be able to make firmer claims about the stability of these three frames, the existence of additional frames and any shifts in framing that occurred as the semester progressed. We use the preliminary evidence in this appendix to illustrate some level of consistency and persistence of the three frames we identified as part of this study.

Conclusion

During her final interview at the end of the PD and BIO14 semesters, there was a fascinating exchange between the interviewer and Ella about something she learned from her experience in the PD:

Ella: So, that's like probably the thing that we sort of touch on in [the PD], asking guiding questions as opposed to like just being like, "Well, that's a dumb idea." Um, so definitely ask a lot more questions in all my sections including when we're like doing a discussion and being like, "Can you just say more about that?"

Interviewer: Yeah.

Ella: Like I felt weird about that.

Interviewer: It's hard to do.

Ella: Yeah. But, then you realize like when you say that the student is like, "Oh, okay. I'll say more about it."

We view this realization by Ella as one that was explicitly born of the PD. Her newfound recognition that simply asking students to elaborate can, in fact, encourage them to elaborate, is precisely something that we discussed in the PD (as Ella mentions here). This approach to student ideas is also an approach we modeled in our PD as the instructors. Ella's note of this concept of asking for elaboration being something that we "touch on in [the PD]" leads us to think that perhaps she is referencing both the explicit and modeled aspects of this approach that we implemented. Certainly, this moment from Ella's interview indicates that the PD itself helped her feel more comfortable (e.g., less "weird") with interrogating student ideas rather than judging them.

Another informative interview quotation came from Charlie's post-interview. When asked about his experience in the PD, Charlie commented about the nature of taking a PD with other TAs, saying: "Like I think that (discussing moments with other TAs) was good, just because it wasn't like ... it was more like connectiveness and we were all, like, in the same boat." One of the design elements of our PD was to incorporate the 'problems of practice' environment that other researchers have used prior (Scardamalia, 2000; Mikeska, Anderson & Schwarz, 2009; Dini, Jaber & Danahy, 2021). We wanted our TAs to feel comfortable discussing challenging

teaching situations because they were discussing them with other members of their cohort who were likely experiencing similar challenges. Charlie's description of all the TAs being "in the same boat" was exactly the feeling we were trying to cultivate.

In looking at the discourse in Moment Two from Study Three above, we see evidence of a group of TAs who had been working together for weeks, feeling a level of comfort with sharing ideas. The tone of conversation between Ella, Sadie, Susan and Jake was not one that indicated independent ideas being shared like that of a brainstorming session. Instead, each TA was nodding along as the others spoke, and the tone of conversation was one of a *building* of a shared pool of ideas on how to respond to Jamie's idea. This constructive tone, we believe, was born out of the problems of practice or 'same boat' environment that Charlie describes in his interview.

All told, we think that the Studies above and the interview quotes from TAs presented here drive at three main elements of our PD having encouraged the TAs to develop more responsive engagement with student ideas: openness of intentionality on the part of the PD instructors, modeling responsiveness in a meta-fashion by the instructors, and the development of a problems of practice environment among the TAs in the PD. We conclude this dissertation by explicating on these components with respect to future PD design.

a. Recommendations for Future PD Design and Implementation

i. Openness of Intentionality

We as instructors of the PD, took a very overt approach to describing our goals of the PD to the TAs. We were clear from the very beginning, that we were going to push the TAs to focus on the substance of student thinking. We told them during the first meeting that they may find this difficult, but that we would continue to guide them in this way even when it felt challenging. As researchers, it can sometimes feel counter-intuitive or even disingenuous to explicitly

communicate your intentions to your participants. Research words like “blind,” “confounding,” and “biased” can make it feel like intentionality should be withdrawn, hidden or even subverted. In a PD setting, however, we felt that it would be productive and informative to the participants if we let them in on what we were up to. If our expression of intentionality influenced the TAs to work harder at attending to student thinking...well, was that not the point of the PD?

We want to be clear here, that there is a difference between PD design and study design. While we designed the PD with a goal of explicitly telling our TAs what we were trying to encourage them to do, we did *not* design our research studies with a particular outcome in mind. Had the TAs *not* shown evidence of engaging in responsive conversations and discussions, our analyses would still have been carried out. That is, the design of our analyses was not dependent on specific results. However, we see evidence in the moments above as well as in Ella’s postinterview conversation, that the impact of our PD was enhanced by our specific and expressed intentionality, a quality of our PD that we recommend including in future iterations.

ii. Modeling Responsiveness as PD Instructors

The meta-component of our PD involved us, as instructors, modeling responsive practices in the way that we engaged with the TAs. We frequently pushed TAs to elaborate on their thinking by asking them to “say more about” their ideas. Another responsive practice we put on display in the PD was simply allowing time and space for the TAs to engage and converse.

It can be challenging for instructors of any course to simply provide space in the form of silence. As instructors, we can often interpret quiet or non-responsiveness to prompted questions as evidence that students do not know the answer or are simply not comfortable giving voice to their ideas. Evidence has repeatedly shown that allowing time and space for students to fill that

silence can be productive (see Ball, 1993; Hammer, 1997; Engle & Conant, 2002; Maskiewicz & Winters, 2012). As the PD instructors, we often ran into that very situation. In Moment Two from Study Three above, for instance, after asking whether the TAs had “any thoughts” about Jamie’s idea, there was nearly 4 full seconds of silence before Ella responded. Four seconds of silence in a classroom setting, after the instructor asks a question, can feel like an eternity! But by providing the space and waiting until a student voiced an idea, we were demonstrating an approach teachers can use to draw out ideas – the first component of teaching responsively. In this instance, providing that space proved to be highly productive as the ensuing discussion went on among TAs without any involvement from the instructors.

Modeling practices like providing space, asking questions driven at encouraging elaboration – pedagogical practices that are aimed at eliciting and responding to student thinking – was something we purposefully did throughout the PD semester. Whether the TAs explicitly picked up on this or not is not entirely clear. Our interpretation of Ella’s epiphany about “asking students to say more” is that she came to this realization in part after watching it play out in the PD. Another interpretation is that her recognition of this phenomenon was born out of some specific conversations that occurred in the PD. Either way, we find it hard to imagine that our practices as PD instructors were not at least subconsciously recognized by the TAs.

We see evidence of our practice enhancing discussion quality in the PD as being a metaexample for the TAs to connect to their practices enhancing discussion quality in their teaching labs. A more directed study of this connection would require interviews with more targeted, structured questions (even something with some open-endedness like “What elements of the PD influenced your teaching the most?”). However, we feel confident that our modeling of responsive practices helped the TAs experience the benefits of those practices and therefore helped encourage them to implement similar practices in their engagement with student ideas.

As such, we would suggest implementing this meta-level of structure into any PD aimed at encouraging student-centric pedagogy.

iii. Problems of Practice

As Charlie noted in his post-interview, the feeling of all of the TAs being in the “same boat” was “definitely good.” The notion of a shared-experience environment making participants of a training feel more comfortable giving voice to their own challenges and ideas is not a novel one. The concept of ‘problems of practice’ is spelled out by Mikeska, Anderson & Shwarz (2009) and is used inherently in many instances of professional development (see Kazemi & Franke, 2004; Schussler et al, 2008; Olmstead & Turpen, 2017; Dini, Jaber & Danahy, 2021).

One of the challenges of professional development is the very nature of what professional development means: teachers engage in training because they have a need or desire to become more effective teachers. Engaging in discussion in such a setting can feel very vulnerable. We tried to create a setting in which TAs would feel comfortable both sharing their struggles but also simply engaging in conversation. Noticing, interpreting and responding to student ideas – even in video not from their own class – was likely a new pedagogical approach for our TAs. Engaging in this kind of practice aloud with other instructors could feel intimidating. By having the TAs work together collectively to discuss video clips with a responsive approach, we think that we developed a PD culture that was open to any and all TA interpretations and ideas. No one in the room was an expert, and so new ideas could be looked at as new, rather than wrong. As evidence of the benefit of this shared problems of practice culture, we present one final interview quote from Susan’s post-interview:

By looking at other T.A.s' video, [it] really helped me out because I just kind of got the idea, okay, okay, so this is how other people are doing this thing. But I might do it

differently. So is that great? Is that bad? Or is that, do I need to improve that? So I think that's really helpful.

We have been discussing the benefits of problems-of-practice as it relates to having the TAs work together in discussion. Here, Susan gives voice to the benefit of another element of this shared-experience environment: watching video clips from each other's labs. By literally *seeing* the shared experience of the teaching labs in the PD, Susan articulates how it helped her feel more able to critique and consider her own pedagogical practices.

Designing our PD to cultivate the problems of practice environment that emphasized the shared experience among the TAs both of teaching the BIO14 labs and also engaging in responsive practices in the PD was useful to our efforts as PD instructors. We believe we see evidence in the moments of analysis above as well as in interview quotes from the TAs, that this PD culture supported the TAs in contributing their ideas and being open to adjusting their own practices. We recommend that future similar PDs design and implement a problems of practice approach.

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