Student-Centered Pedagogy in Biology: Developing a Responsive Teaching Professional Development for Graduate Student Teaching Assistants

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Abstract

Responsive teaching is an approach to pedagogy that encourages teachers to elicit, notice, attend to and respond to the substance of student thinking. There is evidence that this style of instruction in STEM classrooms can increase student depth of understanding of topics as well as encourage more equitable participation and self confidence in students. The inherent uncertainty about what kinds of ideas students might have and how best to respond to those ideas can make responsive teaching challenging for practitioners. Novice teachers may feel particularly challenged to grant students agency over their ideas and allow students to interrogate non-standard knowledge. Our broad goal is to design a professional development for a particular group of novice teachers – graduate student teaching assistants – to help train them to incorporate responsive practices into their teaching methods. The more specific goals of this paper are to explicate the benefits and challenges of this approach to instruction and then to explore the literature on teacher training to begin to design and develop the professional development. We intend to design the professional development to build on resources that these novice teachers may already possess – topical expertise and openness to multiple teaching strategies – and to use methods present in prior studies to most effectively train our teaching assistants to begin to draw out, listen for and respond to student thinking and ideas in biological science.

Introduction

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). We designed the laboratory curriculum, taught exclusively by biology graduate student teaching assistants (GTAs), with the intention of exposing students to 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.

Teaching BIO14 had challenging aspects that were largely related to the uncertainty of what would happen in lab each week. Student engagement with questions like the one above 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. Deciding what to do in these moments presented a challenge for our teachers, the GTAs. Students were also given space to develop research questions and to design experiments to test those questions without being restricted by pre-determined experiments and protocols. Removing these constraints on students meant that unanticipated ideas that were not planned for came up frequently in lab each week. Next, I present an example from a BIO14 lab that examines an interaction between a GTA and student that revolves around a student-driven idea.

The above question about comparing mutation rates across species led to a moment in which a student gave voice to an idea for which the reasoning was unclear, creating a scenario in which the

GTA was confronted with a decision on how to handle that lack of clarity. In response to the question, Nick (and undergraduate student in the lab), chimed in by stating his belief that humans have a higher mutation rate than *E. coli* bacteria. In trying to justify this claim, Nick asked the GTA whether or not "mutation rate include[s] silent mutations that occur in, like, non-coding regions of DNA?" Nick's question created a moment in which the GTA 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, GTAs 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 is conceivable (and perhaps even likely) that the GTA felt 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 that do not alter protein structure and thus have no observable phenotypic effects). This information was accessible to the GTA and could have been used in this situation to answer Nick's question.

Another move available to the GTA in this moment could have been to turn Nick's question over to the class: "What do you guys think? Do the mutation rates we are considering here include silent mutations?" This kind of move, especially early on in a semester may signify to students that it is both acceptable and expected for them to interrogate each other's ideas and chime in with their own thoughts. Of course, this move would also carry the risk of being met with reticence on the part of the students to engage in this kind of idea-critiquing. Given the early point in the semester in which this moment occurred, it is plausible that the students wouldn not yet feel comfortable enough to comment on an idea from another student, instead opting to let the teacher provide the answer.

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 GTA asked Nick a simple question: "Why do you ask?" By making the move of asking Nick to say more about his idea (a la Duckworth, 2001), the GTA communicated an interest in Nick's thinking about silent mutations but also did not volunteer an interpretation of the reasoning being the thought.

By essentially asking Nick to elaborate, the GTA in the actual 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 have phenotypic effects ("…generally gonna be in a coding region…"), and in fact 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 that logically would occur in humans accounts for the higher overall mutation rate of that species compared to a species like *E. coli* which experiences mostly phenotypically impactful mutations.

By asking Nick why he was asking about silent mutations, the GTA 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 GTA did not ask any of these questions or push the class to further investigate Nick's idea. Instead, the GTA 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 GTA 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 GTAs response to Nick's idea, and Nick's resulting willingness to elaborate can be viewed as the start 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.

Our aim for these labs was to push students to engage in the doing of science, including but not limited to activities like discussion and interrogation of ideas, development and design of research questions and experiments, and interpretation and presentation of data. Facilitating student engagement with these types of activities requires a classroom culture in which students have agency over their ideas and thinking and feel comfortable sharing and discussing those ideas and thoughts. The simple question the GTA asked of Nick in this example is a student-teacher interaction that we want to encourage our GTAs to strive for in lab: encouraging students to dive into their own thinking and further articulate their ideas.

Pedagogical Approach: Responsive Teaching

We aimed to devise a targeted professional development for GTAs that would help them develop a specific approach to handling student ideas that arose in the labs. The goals of our training were to help the GTAs get practice at noticing the presence of student ideas, attending to the substance of those ideas and responding to those ideas in ways that elevated their importance and granted agency to the students. In light of these goals, we believed that *responsive teaching* would be a useful approach for our GTAs to take towards instruction in the lab.

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 attending to and responding to the substance of those ideas (Robertson, Scherr & Hammer, 2015). Our goal with the lab curriculum was to create an environment in which students developed their skills as novice scientists with respect to asking questions, designing experiments and interpreting results. Managing such a classroom environment tasked the teachers with granting students agency over their own thinking and pushing on that thinking to further develop student-generated ideas. The applicability of responsive teaching given our goals for the lab quickly became apparent and led us to consider the design and development of a responsive teaching-specific training for our GTAs.

Benefits of Responsive Teaching

The lab curriculum charged undergraduate students with engaging with science in ways that involved discussion, design and interpretation. We aimed to construct a classroom culture that cultivated these skills and supported students engaging in these ways by building up students' confidence and comfort in sharing their own ideas and interrogating the ideas of others. In a responsively taught classroom, students are encouraged to feel that their scientific ideas and the ideas of their peers have intellectual merit (Ball, 1993; Maskiewicz & Winters, 2012; Hammer, 1997; Warren et al., 2001).

Furthermore, the lab curriculum was designed to elicit class discussions about science topics that included the kind of disciplinary argumentation present in professional scientific research labs. That is, one of the goals of the lab was for students to learn to interrogate each other's ideas both in small group discussions and in whole class activities. 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 who participates and the overall intellectual quality of students' contributions (e.g. 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 responsive teaching – 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 intend to train our GTAs in similar practices so that they can begin to facilitate student comfort with generating, sharing and considering ideas in the face of lacking disciplinary expertise.

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 also 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 hope our GTAs will work to elicit in our labs. By training our GTAs to practice attending to student thinking and responding in ways that position the students as owners of ideas, we expect to begin to see the emergence of similar kinds of substantive discussions in our labs.

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. Noticing and attending to student ideas can be difficult! First, noticing in the moment that a student has an 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 maybe be particularly difficult for novice teachers like GTAs. Goertzen, Scherr & Elby (2010) studied the underlying beliefs that physics GTAs had that caused them to focus largely on the canonical correctness of student ideas. The GTAs 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 GTAs 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 GTAs, it could prove to be a challenge to overcome. Shifting this notion towards one that places responsibility on the part of the teacher for drawing out ideas and attending to the potential merit of those ideas will be a central part of our responsive teaching training. The pressure GTAs might feel to listen for and notice the canonical correctness (or incorrectness) of student ideas likely comes from their own experience as students rather than their current positions as researchers. This tendency to teach the way they were taught is referred to by Dan Lortie (1975) as "the apprenticeship of observation." While GTAs are actively engaged in science in their own work 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. Overcoming epistemological beliefs about teaching like Julian's and encouraging GTAs to attend to the substance and potential merit of student ideas may prove challenging, but will be addressed in the development of our training.

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 in particular are often well-rooted in accepted 'knowledge' and ways of thinking. Prior to her analysis of particular 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 incorrect and certainly not in line with the accepted knowledge in mathematics. A teacher unconcerned with creating a responsive classroom environment might have moved to simply correct Sean's fallacy 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 enough in the field. 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, 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. On the other hand, the potential for the nonstandard knowledge being offered up by Sean to confuse the class also 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. This exercise could have ultimately wasted class time that could have been spent on ideas more grounded in correctness. 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.

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. The benefits of responsive teaching for students are driving us to develop a professional development for our GTAs that will help them overcome these challenges to create a responsive classroom culture that values, elevates and builds upon student ideas and thinking.

Resources GTAs 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 GTAs 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 GTAs were given opportunities to reflect on their own teaching practices in both writing and discussion. This reflective seminar helped seven GTAs develop insight into teaching practices as well as discover the value of reflective discussion (Schussler et al., 2008).

Schussler et al (2008) noted that GTAs in the seminar showed a willingness to question traditional teaching approaches and an openness to considering alternative practices. A GTA 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 GTAs 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 a responsive teaching professional development could tap into to help encourage GTAs to adopt more responsive instructional approaches and strategies that focus more primarily on student ideas and thinking.

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

While not yet professors, our GTAs have a level of canonical expertise in biology that stems from recently completed (and oftentimes, currently ongoing) coursework. Therefore, energy and time that might have been spent on clarifying and understanding the content that they are teaching can instead be focused on developing a pedagogical approach that centralizes student ideas (Ball, Thames & Phelps, 2008; Thames & Ball, 2010). For instance, if our GTAs for the biology labs were psychology students, it would be necessary for those GTAs to spend large quantities of time and effort learning and mastering the content they would be teaching, leaving little time for focus and effort to be put into developing a responsive pedagogical approach. Since our GTAs already possess the content mastery, our professional development can focus exclusively on encouraging and developing responsive teaching abilities.

Furthermore, as a result of their involvement in research, GTAs regularly engage in making sense of ideas that their peers, colleagues and advisors bring up. While GTAs might view the ideas of fellow researches as having more value than the ideas of inexperienced undergraduate students, the practice at making sense of those ideas is a resource we hope to leverage in our professional development.

Our goal with the professional development is to give our GTAs a low-stakes, group-oriented environment in which to practice responsive teaching techniques. We want to give GTAs 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 are not aligned with traditionally accepted disciplinary knowledge. We want to build on resources that GTAs already have – 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 (PD), 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 they possess to address the challenges associated with responsive teaching.

Review of Professional Development Approaches

The remainder of this review will focus on examining examples of professional development that were aimed at training teachers to notice, attend and in some cases respond to student thinking. While novice teachers (in particular, graduate student teaching assistants) in biological science are of primary interest here, the general lack of study of such a small subpopulation of teachers will necessitate the inclusion of an examination of studies that look at teachers with a variety of experience levels across multiple STEM fields.

As noted, the challenges our GTAs face with this instructional approach include:

1. Overcoming distractions to notice student ideas,
2. Shifting beliefs about teaching away from pushing students towards correct answers and towards guiding students to share and interrogate ideas
3. Coping with concerns about propagating non-standard knowledge by responding to student ideas in ways that encourage disciplinary engagement and argumentation.

We intend to develop a professional development that addresses these challenges by building on resources that GTAs already possess:

1. Willingness to consider novel pedagogical approaches
2. Disciplinary content mastery
3. Experience with making sense of disciplinary ideas

Through a review of relevant literature, I have identified two types of activities frequently used in professional development aimed at supporting teachers in noticing, attending and responding to student thinking: examining and discussing moments from classroom video and examining and discussing examples of student-produced artifacts. This review will investigate the efficacy of these activities in addressing the challenges of responsive teaching and building on the resources possessed by GTAs.

- ***Classroom Video Analysis***: Observing video clips during professional development from live instruction has been used as a way to help teachers develop their skills at noticing and attending to the things that happen in a classroom (i.e., student articulations, teacher moves, etc) away from the pressures of a classroom.

- ***Student-Produced Artifact Analysis***: Practicing focusing on identifying and providing feedback on student thinking in written assignments in a professional development setting alleviates some of the pressure of having to notice these moments during live instruction.

Classroom Video

Observing and discussing video data of live classroom instruction can be a powerful training tool for developing teaching practices, particularly as a way to provide teachers with practice noticing and engaging with student thinking and ideas. Classroom video is a tool that we intend to use in two ways in our professional development meetings:

1. Observing video of students talking and doing lab activities as a way to practice shifting attention to notice 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 as a way 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 low-stakes way for teachers to get practice at listening for ideas in face of distractions (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), watching video of students engaging in science 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 stating 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 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! We will ask our GTAs to engage with classroom video of their own and each other's students talking and doing lab activities as a way to practice recognizing when students are having and sharing ideas.

Using classroom video of student moments to help encourage a shift in teacher belief about teaching towards attending to the merit and substance of student thinking is a bit trickier. A part of watching classroom video clips is the ensuing discussion among PD participants about what they noticed and attended to. We expect that GTAs may lean towards attending to any factually incorrect aspects of student ideas (as suggested by Goertzen, Scherr & Elby, 2010, and prior work in these labs 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 intend to make clear to the GTAs that what we are asking them to do – attend to the substance of the student ideas even if they are "wrong" – is hard! We want our GTAs to feel comfortable discussing this challenge and creating a community feeling that allows them to support each other in changing this perspective.

Mikeska, Anderson & Schwarz (2009) suggest that engaging preservice science teachers in dialogue about challenges of instruction in professional development settings can help them reason about how to handle such problems of practice during live instruction. Watching video of students at work, challenging the GTAs to attend to the substance of their ideas (while not focusing on the canon), and allowing the GTAs to open up about the challenges of doing that is how we intend to start driving a shift in how they think about student ideas.

We also intend to leverage the GTAs' content mastery and experience with making sense of ideas while discussing these videos to keep our discussions focused on pedagogy and instruction rather than the topic at hand. For instance, if our PD class watched video of Nick's articulation of his ideas about silent mutations described earlier in this paper, we would take advantage of the fact that the biology GTAs in the room have expert-level understandings of what silent mutations are and instead focus our discussion on the pedagogical notion of working to attend to the potential merit of Nick's idea. Showing the clip in PD and intentionally positioning Nick as simply the haver-of-the-idea, we would push the GTAs to work to make sense of this idea rather than evaluate it for relevance or correctness. The feelings of community support that are generated through these reflective discussions also helps alleviate some of the anxiety and stress that novice teachers often feel (Garrison & Kanuka, 2004; Little, 2003; Little & Horn, 2007; Printy, 2008).

The literature suggests that using student-centered video clips in a PD setting can help teachers get practice at noticing and recognizing the presence of student ideas without having to be distracted by other classroom demands. Using this tool as a way to begin shifting GTA beliefs about their roles as teachers is less clear, but is necessarily driven by the nature of the discussions that follow viewing of the clips. A problems of practice community feeling in the PD would seem to be one approach to instigating this shift; leveraging resources the GTAs already possess to help focus the discussions on pedagogy over content is another approach we intend to apply.

There is also evidence that instructors are capable of noticing and critiquing teaching practices when watching them on video (Levin & Richards, 2011; Rosaen, et al., 2008; Seidel, Bromberg & Renki, 2013). A challenge of responsive teaching for instructors is learning how to craft responses to student ideas that encourage disciplinary engagement without generating confusion over nonstandard ideas. Using classroom video that shows teachers making moves in response to student thinking will give our GTAs opportunities to see what happens and to critique the results.

Levin and Richards (2011) conducted a professional development session with novice science teachers at the university level aimed at helping teachers learn to attend to student thinking. As part of the professional development, the researchers showed video of moments of instruction in which teachers attended to and responded to student thinking as examples of good practice (Levin & Richards, 2011). Discussions about how to implement these practices during live instruction went hand in hand with watching these videos and the teachers began to show improved ability to engage with student thinking in their own classes as the PD progressed (Levin & Richards, 2011). Watching video of moments of instruction in which teachers engage with student ideas is a way to show the GTAs in the PD that student ideas can be central to a discussion without encouraging prolonged focus on nonstandard ideas that could be confusing.

There is also evidence that having teachers watch themselves teach can also be useful for developing responsive practices. Rosaen et al (2008) found that teachers notice their abilities to facilitate discussion when watching video of their own teaching practices. Seidel, Bromberg & Renki (2013) found that teachers who watched their own teaching in video were highly invested in considering the instructional moves they had made and were noticeably motivated to attend to relevant components of teaching. While these studies are not directly asking teachers to consider responsiveness, the teachers' willingness in these studies to focus on student discussion and instructional moves is encouraging for our purposes. As noted above, GTAs may have an openness to novel approaches to teaching. Leveraging this resource along with the findings from Rosaen et al (2008) and Sediel, Bromberg & Renki (2013) suggesting that watching self-video tunes teachers into instructional practices seems fruitful for our PD. After spending time in the PD focusing on noticing and students' ideas, we will ask GTAs to bring in video of themselves teaching and spend time discussing the instructional moves that get made and how the teacher responses to students' ideas impacted the flow of discussion. Applying this practice in the PD will enable us to work as a group to see patterns that reflect the benefits of responsive teaching for students – when student ideas are elevated, and teachers grant agency to students, rich, equitable, topical discussion often ensues.

Student-Produced Artifacts

Examining student-produced artifacts (including written assignments, drawings, data manipulations, etc) for evidence of student thinking can eliminate some of the distractions present in live moments of instruction (social interactions, student behaviors, etc). However, there are new kinds of distractions that can take teacher attention away from noticing student thinking: formatting issues, grammar and spelling, and canonical correctness (see Hill, Gouvea & Hammer, 2018). Talanquer, Bolger & Tomanek (2015) studied 32 prospective secondary school teachers' qualitative written responses to student work and found that these teachers tended to focus on the description and qualification of student work. Attempts by teachers to notice and make sense of student ideas in writing were rare (Talanquer, Bolger & Tomanek, 2015).

However, there is evidence that when teachers engage with student thinking in written form they are capable of noticing and attending to the substance and merit of student ideas at least occasionally (Hill, Gouvea & Hammer, 2018). Attending to ideas in writing gives teachers more time to think about the substance of student ideas without the pressures of crafting an immediate response to a spoken thought. Of course, the range of ideas that a student could possibly articulate in a written assignment are somewhat dependent on the assignment itself; thus, in addition to noticing student thinking in writing, it is also important for a teacher to attend to what the student was tasked with doing in the assignment.

We intend to introduce student artifacts into our PD as another way to practice noticing the presence of student ideas and attending to the substance and merit of those ideas. Unlike the studies noted above, our PD will not be tasking the GTAs to assign grades to student work. Kazemi & Franke (2004) conducted a professional development with ten elementary mathematics teachers in which they used written student work as a tool to train teachers to notice how students were thinking about basic math. The researchers particularly focused on how collective analysis of student work in a professional development setting not only led to teachers becoming more skilled at noticing and pointing out evidence of student thinking, but also to the development of teaching trajectories that were specifically based on student thinking (Kazemi & Frank, 2004). While initially uncertain about how to attend to student thinking (or even what constituted student thinking in written work), through collective practice, the teachers in the professional development got quantifiably better at noticing and pointing out examples of student thinking (like student-generated algorithms) as the training progressed (Kazemi & Franke, 2004).

Like with the classroom video, we will be very transparent about the goals of looking at student work – find and identify student ideas and try to make sense of them. Once again building on the resources that GTAs already possess, we will ask them to examine student written work and try to determine what the students are up to with their words. This might sound simple in practice, but we want the GTAs to feel comfortable discussing the challenge of shifting their attention away from evaluation for correctness and towards sense-making. By removing the classroom-related pressure of grading written work, we expect the GTAs to be more open and willing to consider this novel way of interacting with written work.

We also intend to use student written work to help our GTAs overcome the challenges associated with responding to student ideas – namely, encouraging agency without propagating confusion grounded in nonstandard thinking. An additional outcome of Kazeme and Franke's (2004) professional development that used student written work was the development of teachers' skills at responding to student thinking. Several teachers in the PD noticed that students in their classes had developed creative ways to multiply double digit numbers; as a collective group, the teachers found this emergent student way of thinking to be fairly consistent across classes (Kazemi & Franke, 2004). In response to this, the teachers agreed that it would be good practice to allow the students space to work with the numbers in class so that these creative processes would emerge with more frequency (Kazemi & Franke, 2004). In fact, the teachers in the PD began to design lesson plans that specifically carved out time and space for students to have the opportunity to build on their ideas about how to multiply large numbers (Kazemi & Franke, 2004). This type of response to patterns of student thinking that the teachers observed is exactly what we hope to encourage within our PD. For instance, if our GTAs noticed that students frequently brought up silent mutations in their written work about comparative mutation rates, we would hope that what would emerge from a discussion about this is the notion that perhaps this is an avenue of thought worth letting the students explore (as opposed to shutting it down as irrelevant or unconnected to the point).

By using student-produced artifacts in a professional development setting like Kazemi and Franke (2004), teachers showed evidence that they not only honed their noticing and attending skills, but they also began to show evidence of responding to what they noticed in ways that encouraged students to continue building on their thinking. This type of disciplinary response to student ideas is exactly what we ask of our GTAs and while this example takes place within the context of elementary mathematics, it provides evidence that teachers are capable of using student-produced artifacts to develop such a pedagogical approach.

Despite some of the potential distractions that student written work may carry with it, we think that using this tool in a PD setting (coupled with transparency about how we are using it) can provide the GTAs another low-stakes way of getting practice at ignoring those distraction and instead focusing in on student ideas. Furthermore, we expect that through the examination of student artifacts, we will find opportunities to encourage the GTAs to focus more on making sense of what the students are writing (a resource GTAs are honing in their research lives) instead of looking for keyword-based correctness. Through the encouragement of this shift in understanding of what teaching involves, we anticipate some moments like the one Kazemi & Franke (2004) experienced in their PD in which teachers recognized patterns of student ideas and tailored responses to those patterns to build on student thinking, rather than correcting it for a particular, pre-determined course.

Conclusions

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 believe that the benefits responsive teaching afford make it a good instructional approach for our lab instructors to use. 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 GTAs had as instructors of the labs, we identified three specific challenges they might face when asked to teach the labs responsively:

1. Overcoming distractions in the classroom to notice the presence of student ideas
2. 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
3. Developing methods of responding to student ideas that encouraged them to build on their thinking and hold agency over their ideas without propagating canonically incorrect disciplinary knowledge

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

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

Through a review of the literature, we believe that using classroom video in the style of Van Es & Sherin (2010) along with student-produced artifacts in the way of Kazemi & Franke (2004) as tools for giving GTAs low-stakes, collective practice at noticing and attending to student thinking will be productive and generative in our professional development. We intend to give the GTAs space to discuss the challenges they have with shifting their perspectives on teaching towards responsiveness with a problems of practice attitude as in Garrison and Kanuka's (2004) work. We believe that this will help to create the PD environment we are seeking in which GTAs are comfortable talking about their personal beliefs and challenges.

By being transparent in the purpose of the discussions we engage in in the PD, and by purposefully drawing on the GTAs existing resources including their expert-level content mastery and experience with making sense of topical ideas, we think that we can develop the GTAs sense of why it is a good thing to attend to student thinking rather than student correctness. We believe that the discussions we have after watching classroom video or examining student work will provide evidence to the GTAs that they can respond to student ideas in ways that further their disciplinary understanding without pursuing "wrong" or flawed ways of thinking about biological concepts.

As our GTA professional development progresses, we expect to continually need to shift and adjust our approach as developers and leaders to meet the needs and expectations of the GTAs – that is, we expect to be responsive! Applying the tools reviewed in this paper will give us the means and space to have this flexibility. Videos may at first focus on moments of student thinking and then transition to critiquing and developing teacher moves. Student-produced artifacts may first be used to identify the presence and substance of student ideas and later be used as tools to practice responding to patterns of student thinking. The guided reflective discussions that occur in the PD will, by nature, shift and change in real-time depending on the current issues that GTAs are feeling challenged by. The overarching goals of all of the activities and episodes we use in the PD will be to help our GTAs begin to focus on and emphasize the scientific substance and merit present in student thinking and respond to that thinking in ways that drive thoughtful, collective discussion of disciplinary ideas. Overtime, ideas like Nick's will emerge and become part of the fabric of the scientific discussion and investigation, a process that will be guided by instructors and driven by students.

Future Directions

Ultimately, the ways in which the GTAs are impacted by the responsive teaching professional development will be the main focus of my dissertation research. This review has functioned to help design activities and approaches for the PD course itself and the next steps after completing the PD course will be to analyze multiple data sources (GTA interviews and journals, video recordings of the PD and BIO14 lab sections) to begin to understand how the GTAs were affected. I hope to be able to address the following research questions from those data:

1. In what ways did GTAs' attention to student-articulated ideas and thinking shift over the course of the professional development?
    - Specifically, was there any evidence supporting a shift away from attending to canonical correctness and towards attending to the scientific substance of student ideas?
2. In what ways did GTAs' responses to student-articulated ideas and thinking shift over the course of the professional development?
    - Specifically, was there any evidence for a shift away from judging student ideas for correctness and towards engaging with the substance of student ideas?
3. In what ways did GTAs' beliefs about their roles as teachers shift over the course of the professional development?
    - Specifically, was there any evidence for a shift away from believing their primary role was holder of correct knowledge and towards believing their primary role was encourager of disciplinary engagement?

In addressing these questions, I hope to be able to comment more generally on the efficacy of responsive teaching training and potentially propose refinements on the methods of implementing this training. If this research shows evidence of GTAs showing productive beginnings of applying more responsive pedagogical approaches in the classroom, it is our belief that a refinement and honing of the PD design will build on these beginnings, as well as on the resources GTAs already possess, to begin to develop a cohort of budding teachers who teach science by considering the science behind the thinking of their students.

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