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Exploring the tensions science teachers navigate as they enact their visions for science teaching: what their feedback can tell us

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ABSTRACT

This paper reports on inservice science teachers' collaborative feedback to each other on videos of their classroom teaching during debrief sessions. We aimed to understand how the teachers' feedback reflected their vision for science education and how they collaboratively identified and discussed the misalignments between their vision and actual classroom practices. Ten videos of debrief sessions involving 17 K-12 science teachers participating in a teacher leadership professional development program were analysed. The feedback captured the teachers' reflections as they collaboratively identified issues that were important to them and attempted to resolve them together. Our initial analysis of the data led us to frame our study within the literature on critical reflection, democratic practices, and student agency in science education. The teachers had a deep awareness of the need for democratic practices and shared power in their classrooms. Their feedback, however, revealed the tensions that arose as they discussed enactments of each of these tenets in the classroom. This study contributes to the literature on feedback given among inservice science teachers and proposes a professional development model that supports teachers' professional learning in a social and democratic setting.

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Introduction

Limited research is available on the nature of feedback given among inservice teachers on their teaching practices. Most studies have focused on feedback given to preservice teachers by mentors to develop their noticing abilities (Fund, 2010; Schwartz et al., 2018). Others have studied feedback among preservice teachers in microteaching settings (e.g. Amobi, 2005) or their noticing of student thinking and instructional resources in video club settings (Johnson & Cotterman, 2015). Examples of studies on inservice teachers include those focused on teacher noticing (e.g. Ho & Tan, 2013; Luna, 2018), lesson studies (e.g. Bjuland & Mosvold, 2015; Coenders & Verhoef, 2019), and professional learning communities (e.g. Gore et al., 2017; Harris & Rosenman, 2017).

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By reporting on feedback given among science teachers and on how they navigated the complexities of change-oriented teaching, this study contributes to the literature on professional development (PD), democratic practices, shared authority, and student agency. Our study involved a PD program for K-12 science teachers that incorporated elements of effective programs (Darling-Hammond et al., 2017; Garet et al., 2001), in which teachers discussed their classroom videos and collaboratively shared ideas through feedback and reflections over the course of a school year. We sought to use the teachers' feedback as a lens to characterise their visions for democratic practices in science teaching and learning. Grounded in the literature on agency, power, democratic practices, and critical reflection, we explored the following research question: What does teachers' feedback shared in a collaborative setting reveal about the tension teachers navigate as they incorporate change-oriented science practices in their teaching?

Literature review

Teacher thinking through collaborative critical reflection

We were interested in the nature of experienced science teachers' feedback as they engaged in collaborative critical reflection of their lessons. Critical reflection is a process that involves reconsidering presuppositions and assumptions as we try to problem solve (Fook, 2015) and understanding the ethical and moral implications of our practice (Briscoe, 2017; Piliouras et al., 2015). Critical reflection has been used in teacher education in science in many forms (e.g. Fook, 2015; Rymes, 2015). These forms include supporting preservice teachers in methods courses (Shandomo, 2010), providing professional development during a co-teaching clinical experience (Guise et al., 2017), supporting science teachers' discussions around their teaching (Beltramo, 2020), and promoting classroom discourse analysis (Rymes, 2015).

Critical reflection can be understood to have two emphases: (1) 'The broader social context, power relations in social groups, and values and fundamental social questions' (Saric & Steh, 2017), and (2) 'A self-critical, investigative process where teachers consider the effect of their pedagogical decisions on their situated practice with the aim of improving their practice' (Tripp & Rich, 2012, p. 678). As teachers engage in critical reflection under certain conditions, they can see their assumptions about teaching and learning, question the meaning of those assumptions, and find ways to change those assumptions (Liu, 2015; Saric & Steh, 2017). We drew from critical reflection because of its consideration of power and because it involves more than reflecting on 'how to' or 'what to do.' Rather, it involves questioning our previous understandings, asking 'why' questions, and re-examining problems (Liu, 2015; Piliouras et al., 2015; Saric & Steh, 2017). Teachers' collective experiences in collaborative settings can elicit critical reflection in a way that allows teachers to realign their stance, problem-solve together, and support each other as they strive to improve their practice (Briscoe, 2017). These characteristics of critical reflection distinguish its use of the word 'critical' from the adjective that indicates disapproval or negative judgements.

When teachers collaboratively analyse and critically reflect on their practice under particular conditions, they can challenge their notions about their practice and develop ways to improve it. For instance, in the Piliouras et al. (2015) study, teachers

engaged in discourse analysis and discovered that their teaching strategies did not support inquiry. They found that instead of being encouraging, they were discouraging students' and groups' expression of ideas and monopolising the discussions. This realisation led the teachers to re-evaluate their instruction and discuss potential actions to take, pointing to the important role critical reflection can play in improving practice.

Studies have shown that when supported, teachers can deepen their critical reflection in collaborative settings over time. For example, Beltramo (2020) explored the development of critical reflection of two science teachers participating in cogenerative dialogue, 'that cent(red) on identifying and addressing problematic areas of classroom teaching and learning' (p. 86) with their students. Findings revealed that while most of the discussions were at first technical and centred on the day-to-day occurrences common to teaching, towards the end of the five-month project, the teachers did eventually discuss and reflect upon 'big idea' issues related to equity and student-centred instruction. While many of these issues were left unresolved, the two teachers deepened their critical reflection to examine their teaching from different perspectives and to consider the social and political complexities of enacting equity-oriented pedagogy. Yoon and Kim (2010) also found that teachers' critical reflection became more sophisticated over time. In their study, teachers shifted from expecting issues to be resolved through discussion to appreciating the process of reflecting and recognising the complexities of the profession.

Additionally, the deliberate grouping of teachers can support collaborative critical reflection and help teachers develop their reflective skills over time. For example, Horn and Kane (2015) explored how mathematics teachers at different levels of 'sophistication' (as measured by a rubric on Complex Instruction) responded to opportunities for professional learning in workgroup conversations. They found that the sophisticated teachers engaged in richer conversations that created more opportunities for learning than the beginning or emergent teachers. Other studies on critical reflection have explored the role of a facilitator in encouraging teachers to shift from offering alternative strategies to thinking deeply about the social and political complexities of the problem at hand (e.g. Clarà et al., 2019). All of these studies point to the importance of collaborative critical reflection in supporting teachers as they recognise and discuss the situative nature of teaching and appreciate it as a process rather than as a means to an end (e.g. Yoon & Kim, 2010).

Illuminating issues in science education

Critical reflection can serve to illuminate issues of equity and democratic practices in the science classroom (Behizadeh et al., 2019). Among the considerations embedded within democratic practices and shared authority in the classroom is student agency. Research on student agency in science education is driven by the growing gap between students' lives and their learning of science (e.g. Balgopal, 2020; Dimick, 2012). Arnold (2012) defined *student agency* as 'the student's positioning as responsible for action in science learning conversations' (p. 1). Other scholars have depicted agency as the action that students take to attain their goals (of gaining scientific knowledge) and contribute as members of a community (Barton & Tan, 2010; Miller et al., 2018). Research reveals that agentic positioning enables students to make decisions that result in increased

levels of engagement and meaningful changes in their education (Barton & Tan, 2010; Schenkel & Calabrese Barton, 2020).

Student voice is an important consideration for enacting agency in a situated and socially interactive learning context. Student voice has two dimensions: student *perspectives,* where students share their ideas about their own schooling; and student *participation,* where students enact their ideas for learning (Furman & Barton, 2006). Student agency is also impacted by the power negotiations between teacher and students (Ottander & Simon, 2021; Schenkel & Calabrese Barton, 2020). The nature of these interactions determines the level of student interest and the ways in which they express themselves in the classroom, ultimately impacting their learning (Basu, 2008; Dimick, 2012). Although power is inherently present in classrooms, teaching strategies and ways of communicating during instruction influence the power dynamics between the teacher and students. For instance, if the teacher unilaterally makes decisions about the curriculum, lessons, methods of instruction, and classroom structure, then the students' voices, actions, and choices in their learning are constrained, and meaningful learning is hindered (Brunsell & Fleming, 2014; Upadhyay, 2006). Providing opportunities for students to communicate their thoughts and ideas during instruction and problem-solving distributes power, resulting in shared authority in the classroom (Schenkel & Calabrese Barton, 2020). Balanced teacher-student power relationships and increased opportunities—especially for students of colour—contribute to engagement (Arnold & Clarke, 2014; Sharma, 2008).

Agency, shared power, and democratic practices herald the principle of *neutrality* where all students––regardless, for example, of their race, gender, income level, or the resources available to them––have opportunities to succeed in science classrooms and science-related careers (Basu & Barton, 2010). These tenets mitigate power differentials in science classrooms and structure learning to put students at the centre of science learning (Basu, 2008; Schenkel & Calabrese Barton, 2020). Rather than being at the periphery with no power in shaping their inquiries in the classroom, students participate in the doing and learning of science.

Methods

The Context

This research is part of a project on science teacher leadership developed by the University of Massachusetts and implemented at seven universities. At our site in northeastern United States, we worked with three cohorts of K-12 science teachers from five local school districts. Each cohort participated for two years between 2013 and 2018. The research described in this article is on Cohort 1, who participated in the project from 2013–2015. Teachers in the project had at least three years of teaching experience. The program aimed to enhance teacher leadership through reflection, teamwork, and individualised leadership plans. In Year 1, the teachers, also called 'Fellows', worked on collaborative reflection and participated in PD that supported their role as change agents. They then undertook independent projects that supported district initiatives in Year 2 (Klein et al., 2018). In this paper, we focus on Year 1 activities.

In the first year of Cohort 1, 17 Fellows focused on collaborative reflection around their video-recorded classroom episodes. These teachers worked in vertically-aligned

groups for four months in the fall (the first half of the school year) and horizontally-aligned groups for four months in the spring (the latter half of the school year), with each group consisting of four to five teachers. In creating the vertical groups, we grouped heterogeneously across grade levels (from elementary through high school) with each group representing a science content area (biology, chemistry, physics, and earth science). For the horizontal groups, the teachers were grouped by grade band (elementary, middle, high school), regardless of the primary content area taught. Through these intentional groupings, we were attempting to provide conditions for meaningful discussions (Horn & Kane, 2015).

Groups met in debrief sessions for at least one hour per teacher to offer feedback on the teacher's video. These meetings occurred once a month with one meeting devoted to each teacher. Before the first meeting, Fellows set norms for giving meaningful feedback in supportive ways. Next, each teacher recorded an entire class period and shared the video with their group prior to their debrief meeting. The other Fellows were responsible for viewing the video before the debrief meeting. To begin each of debrief sessions, the observed teacher gave an overview of their lesson and sought feedback by asking for 'warm' as well as 'cool' feedback. These exchanges served as a springboard for further discussions on issues of interest to the teachers.

Our PD model was developed to align with features of high-quality PD programs. For example, our program was sustained over time (with each teacher participating for two years), teacher-directed, content-based (Kennedy, 2016; Tunney & van Es, 2016), and relied on the expertise of the participants, unlike the workshop model often given by outside experts who are disconnected from the realities of the classroom (Garet et al., 2016). Experiences and insights, given through peer feedback, drove the debrief discussions to focus on issues that emerged from the teachers' practices. Because the fellowship was selective through an application process, only teachers interested in learning from it and enthusiastic about the program participated, contributing to a collaborative setting where everyone was committed to the goals of the program.

Although the debrief sessions were a part of a PD program, the researchers intentionally did not participate in the debrief process. This decision was in keeping with the teacher leadership focus of the PD program and with the desire to give the teachers agency and leadership opportunities. We also did not want any illusion of an evaluative component to the experience. That said, the Fellows came together as a whole group once a month to discuss their overall progress and to engage in related PD activities. At the beginning of the year, before the debrief sessions, the researchers led the Fellows in mock debriefs using existing videos from the other project sites. As part of the discussion, researchers had Fellows generate characteristics of meaningful feedback and had them practice phrasing both 'warm' and 'cool' feedback. The Fellows were also assigned related readings—for example about teaching inquiry-based science (e.g. Banerjee, 2010), and discourse in science classrooms (Osborne et al., 2004).

Data collection and analysis

Data were collected from 10 debrief session videos from the 17 Cohort 1 participants. The other videos could not be analysed because the quality of the video or audio was inadequate. Although only 10 videos were analysed, all 17 participants were represented

in the data because all of the Fellows participated in the 10 debrief sessions. Table 1 shows the professional backgrounds of the participants. All names are pseudonyms, with the bolded names indicating those videos were analysed.

Data analysis was an iterative process that involved coding, categorising, and re-contextualising the feedback. After transcribing the videos verbatim, we identified meaningful segments (Seidman, 2019), and entered them into a codebook. Our first review of the coding focused on three levels adapted from van Es and Sherin (2006): warm vs. cool feedback (or neither), target (teacher, student, school), and content—ways of thinking, pedagogy, climate and management. Two of the authors coded each of the segments independently. Our initial coding resulted in an 83.7 percent agreement rate. Next, we revisited our initial coding scheme and discussed and resolved all discrepancies (Glaser & Strauss, 1967).

We then reviewed the segments in each category, identifying patterns within the data (Glaser & Strauss, 1967). Next, the codes were re-organised chronologically, leading to a re-contextualisation of the data, according to thematic analysis (Braun & Clarke, 2006). This iterative process led to constant revisiting and refining of our research question and constant comparison of the codes (Glaser & Strauss, 1967), allowing us to capture the richness conveyed through the data.

A deeper analysis of the codes helped us identify themes. We decided to focus on the codes and themes identified from the final, more targeted coding process. These themes related to teachers' visions related to classroom roles and included agency, shared authority, and democratic processes (Table 2).

Findings

Teachers' feedback revealed the prevalence and depth of discussions around democratic practices, shared authority, and student agency in science education. These became prominent lenses through which teachers reflected, offered feedback, and asked questions. In addition, teachers spoke of their deliberate attempts to foster these tenets against the backdrop of the lived realities of their classrooms. Table 2 provides an overview of our

Table 1. Participants' professional backgrounds.

Teacher	Grade level and subject taught	Years of experience
Emery	HS biology	>10 years
Tylor	Elementary	5 years
Chris	Elementary	>10 years
Richard	MS science	4 years
Gema	MS science	>10 years
Casey	MS science	>10 years
Ari	HS chemistry	6–10 years
Kyle	HS environmental science	4 years
Olivia	Elementary	10 years
Mia	HS chemistry	4 years
Amelia	Elementary	5 years
Cameron	MS science	4 years
Mack	Elementary	5 years
Stevie	MS science	>10 years
Leah	Elementary	10 years
Kay	Elementary	5 years
Edith	MS science	>10 years

Table 2. An overview of codes and themes.

Theme	Codes	Sub-codes	Exemplar (*w* indicating warm and *c* indicating cool feedback, unless coded 'other').
Enacting a democratic classroom	Sharing power	Student-centred classroom	Trying to get more student-centered and us getting out of the picture. (c)
		Peer-to-peer talk	Provide more opportunities to turn and share with one another or with you … and then discuss. (c)
		Change to classroom structure	Position your students (to) communicate and talk about it … change up from the lab seating to a format more like we are at now. And you outside the circle. (c)
		Backgrounding	Gradually move out of the picture. (c)
		Teacher as facilitator	Us engaging them and how could you be more of a facilitator in the lesson. (c)
	Difficulties in sharing power	Shift from previous practice/education	And you know it is at its infancy … because it is not something that we were taught to do.
		Challenges becoming facilitator	You almost have to stop yourself and say don't 'intervene'. (c)
		Timing	How long do you think we would allow the misconceptions to go on before you actually jump in?
		Time constraints	Those kids are really smart and can be challenged at higher levels, but the problem is we may not have that much time.
		Trust	More independence … is good, but it does require a leap of faith to say 'okay' I'm gonna allow them to work independently for a while.
		Behavior	So, I would not be comfortable putting him in a leadership role. He would steer people in the wrong direction.
Student agency	Incorporating students' ideas	Recognising prior conceptions	Kids come to us with their own preconceived notions … we're bringing those notions to another level.
		Relevance	I love the relevance piece so much, the 'who cares' … I'm going to make a poster and put it in my classroom. (w)
	Ownership of learning	Student responsibility	There were no instructions given verbally … one of the kids … wasn't sure what to do, you were like you need to go and reread the instructions. (w)
		Student input	Maybe have more discussion among the students, like, on the issue of the 'why' factor. (c)
		Student roles	The students decided on their roles, which is kind of important. (w)
		Teacher responses	There were only one or two responses that you did not repeat word-for-word … take away students' sense … until the teacher utters it, it is not real. (w)
		Demonstrating understanding	They … were not going through the motions but were defending their position of what they thought … they were demonstrating in that conversation that maybe my answer is not right, but here is what I'm thinking based on that. So, if you are able to defend a position, it shows that you have some form of understanding. (w)
		Monitoring learning	Maybe having to build upon their own answers and address the misconceptions before actually the teacher addresses the misconceptions. (c)

(*Continued*)

Table 2. Continued.

Theme	Codes	Sub-codes	Exemplar (*w* indicating warm and *c* indicating cool feedback, unless coded 'other').
	Students narrating science	Initiating talk	(You said) this is your classroom; you initiate the talk … I'm just going to sit here and take notes (w)
		Students asking questions to pursue	(You said) what would you like to learn about prokaryotic and eukaryotic cells? (w)
		Co-planning of experiments	[Student] asked can we create a lab, like an animal lab … I said to them you have come up with the idea if it is feasible, we will do it and they were like yea!
		Reporting results and verifying	I thought the kids did a good job at reporting and giving feedback and giving results. I felt I was looking at little scientists. (w)

findings with exemplars of the codes that comprised each theme. We describe how the teachers' visions for democratic practices became a central theme in their discussions and how teachers spoke of the tensions they encountered as they aimed to incorporate these visions into their practice.

The Teacher's role in a democratic classroom

Teachers' feedback revealed questions about their attempts to share authority with the students. Fellows discussed concerns about the teachers' positioning with respect to students and how it might hinder the enactment of a democratic classroom.

Sharing power by taking on a facilitative role

As Fellows discussed their roles in the classroom, they mentioned the power intrinsic in the role of the teacher as an adult authority (Schenkel & Calabrese Barton, 2020; Taylor & Coia, 2006), with the understanding that teachers should work to equalise the power differential between teachers and students. Teachers talked about transitioning from a traditional role to a more facilitative one, putting students in the foreground. As Emery from the biology group noted: 'one of the domains in interacting with your students (is) … being able to reach them on another level other than "I am just the instructor."' She went on to say that 'all our angst (is) trying to get our lessons more student-centred and us getting out of the picture.' These comments point to her vision of the teacher as a facilitator. Through her use of the word 'angst,' however, she alluded to the fact that this vision is not easily realised; it involves deliberate shifts in instruction. Chris, also from the biology group, expressed similar sentiments in a different debrief session when she conveyed that she was trying to 'gradually move out of the picture.' Both visions for a student-centred classroom and illustrated by the description of the teacher being 'out of the picture' reflect Fellows' desire to share power with the students.

Teachers also discussed encouraging student talk as a way of shifting power to the students. For example, Casey, from the chemistry group, commented that 'I definitely realised that the students needed to talk more.' Similarly, Emery realised that she could have been 'using more of their [students] talk' to promote a more student-centred classroom and allowing students to construct knowledge together (Arnold, 2012; Miller et al., 2018). In their 'cool' feedback to their peers, Fellows encouraged

drawing upon the students' thinking to guide the discussions. For instance, Olivia suggested to her colleague that she should 'provide more opportunities to turn and share their thoughts with one another or with you … and ask more open-ended questions as students pose together and then turning, sharing and then coming back to discuss.' Others suggested this model of peer-to-peer talk of using 'talk moves' as a way of 'engaging them' and becoming 'more of a facilitator during the lesson'.

In addition to a shift in focus to the students, the democratic classroom envisioned by the Fellows involved a change to the fundamental structure of the classroom. As Emery noted, the very format under which conversations occur when the teacher acts as a facilitator changes. In commending Stevie, she noted that: 'Instead of one versus twenty-four, now you are doing twelve and twelve that are working simultaneously and gathering feedback.' This contrasts with the traditional notion of the teacher at the front of the room and captures an attempt to equalise the distribution of power in the classroom.

Difficulties of 'letting go'

The teachers' comments often related to their desire to have students discuss ideas, hypothesise, and take active roles in science. Much of the discussion, however, centred around the difficulty of 'let(ting) go'. Fellows acknowledged that sometimes, taking a 'back seat' did not come naturally to them. As Emery noted, 'you almost have to stop yourself and say don't "intervene"'.

Part of the challenge in implementing democratic practices seemed to be related to students' behaviour in the classroom. Fellows expressed concerns about students' ability to manage themselves in groups. In explaining his reluctance, Richard claimed that 'more independence on the students' role (is) good, but it does require a leap of faith to say "okay, I'm gonna allow them to work independently on this for a while."' Despite describing one student as a 'bright student', Casey felt that the student might disrupt other students if given a leadership role in the group because his jokes were 'dangerous' and 'unhelpful': 'So I would not be comfortable putting him in a leadership role. He would steer people in the wrong direction.' Despite such concerns, Fellows agreed that teachers need to 'trust students to remain focused and help each other' (Richard) and help students develop their understanding of the concepts, an essential element of student agency in a democratic classroom (Barton & Tan, 2010).

For many, the facilitative role they aspired to stood in direct contrast to their teacher preparation programs. Chris noted that the teacher should shift from the role of 'put [ting] information to the students as if they are empty vessels' to becoming a 'facilitator'. Despite their reluctance, Fellows acknowledged that 'these vessels [students] come to us already with knowledge … a schema … and we have to develop it.' In a different debrief session on Richard's lesson, Edith expressed that teachers know 'how to teach … giving information,' but complained that teaching is becoming more challenging because teachers are being asked more and more to attend to students' 'preconceived notions' and to 'bring those notions to another level'. Fellows expressed their views that 'this is not how we were taught'. Such views show the challenges teachers experience as they embrace and implement new visions of teaching science. They realised that the image of teachers as 'bucket fillers' (Richard) and students as 'receivers of scientific facts' (Miller et al., 2018) was no longer tenable.

Teachers discussed other factors that illustrated to their reluctance to cede control to their students. The language they used in their feedback illuminated the hierarchical structure of the classroom. Mack, commended Edith: 'You walked around and facilitated the discourse and brought them to the conclusion about your objectives that you wanted.' Although Edith was encouraging peer-to-peer talk, this comment reveals that she still maintained power over determining the conclusion of students' conversation to fit her 'objectives'. This ownership of the curriculum points to Fellows' expectations that they share power with students only when it is safe to do so. Thus, in uncharted territory, when the students' conclusions may be unknown or might not fit the learning objectives, Fellows' comments conveyed that the teacher was expected to use their power to bring the conversation to its predetermined conclusion.

Although teachers expressed a desire to distribute power in the classroom, the power was not always theirs to share. Often, the school's pacing schedule and time constraints left the teachers, and thus the students, powerless. For example, school events curtailed Mia's vision for sharing power. She had anticipated facilitating a student-centred lesson but had to change course due to an unannounced school event. Safety was another consideration in the Fellows' discussions about sharing power. Kyle commended Ari on her ability to work within safety regulations to share power with her students: 'When you're using bunsen burner and things of that sort, I think inquiry is wonderful but I'm thinking safety first … I just support you for allowing to have such a free range and doing these activities and keeping them safe.' These examples point to the lived realities teachers navigate as they consider sharing power with their students.

Time needed for inquiry-based science was also an issue. Aside from lamenting that inquiry-based science 'takes longer', Fellows wondered about the timing of 'letting go', and of directing the discussion to move to the next topic. For example, one discussion centred around balancing open-ended discussions, teacher-led demonstrations, student talk, and direct instruction. Amelia asked about the decision to use demonstrations to save time: 'Could the discourse happen or (can) we do demonstrations before we do the activity and how can students be given more opportunity on what (they) can be tested on?' Here, the teachers discussed the best ways to teach particular content in a democratic classroom while also taking into account time constraints and the realities of testing.

As some Fellows wondered about making these decisions against the pressures of time, Emery commented on balancing student discussions with teacher-directed instruction and what to do when the teacher is not 'satisfied by the answer'. She suggested that the teacher ask questions such as, 'What made you think about that? And how would you change your answer? And if only the student cannot, then I can go on to my next student, I just need to be careful not to be jumping very fast.' She expressed similar concerns about stepping in too early. Fellows discussed the question of when to allow students to take ownership of their learning and when teachers should intervene to guide students away from misconceptions. Amelia pondered the following:

> How long do you think we would allow the misconceptions to go on before you actually jump in? Or in terms of monitoring, is there any way you could allow the students to actually address the misconceptions before you actually address them yourself?

Although Amelia sought ways to encourage students to recognise and address their own misconceptions, her peers did not have immediate responses to this quandary.

Student agency in a democratic science classroom

Fellows noticed students' agency as it pertained to who was discussing, conjecturing, and verifying the science. Overall, the Fellows agreed that power should be distributed, and students should be given more agency. For example, the Fellows provided feedback on how their peers elicited prior knowledge and questions to help them plan and analyse experiments.

Leveraging students' prior knowledge

The Fellows' discussions revealed that they place importance on focusing on the students' ideas, questions, and sense-making (Clarà et al., 2019). Fellows acknowledged that understanding and harnessing students' prior knowledge are ways to promote students' intrinsic self-drive and interest in learning. Mack remarked that, 'I had them talking, trying to pull information based on what they knew. I found it helped me. I would definitely use it again.' In a different session, Edith indicated that students are 'not empty vessels', and that they possess preconceptions that can be nurtured. These comments reveal the importance the teachers placed on building upon students' prior knowledge and encouraging constructive inquiry (Bevins & Price, 2016).

In addition to harnessing students' prior knowledge, Fellows noted instances when students' agency was promoted by highlighting the relevance of science to their lives (Sharma, 2008). For example, Leah noticed that a teacher introduced Charles' and Boyle's laws and then asked the students to think broadly and explain how they thought gas laws were relevant to their lives. Fellows commented that asking students to think about how concepts are useful in their lives kept the students active and engaged. Casey expressed her interest in adopting the 'who cares' question in her classroom. She said, 'I love the relevance piece so much, the "who cares" … I'm going to make a poster of that and put it in my classroom and use that as part of my discussion going forward.' Her comment revealed teachers' resolve to adjust their instruction to incorporate students' interests and align with their daily lives to foster student agency.

Ownership of learning

In considering whose voice should be heard and who should act as the narrator or expert in the classroom, teachers proposed tenets of critical pedagogy (Freire, 1973) to upend or at least disrupt the hierarchical structure of the classroom. Chris talked about giving students ownership of the class and making them feel in control, as opposed to having them wait for directions. During a lesson on photosynthesis, in an effort to cede control to her students, she assured the students, 'This is your classroom, you initiate the talk. I'm just going to sit here and take notes.' Giving students ownership positioned the teacher as a facilitator, whose ideas were perceived as part of the collective view rather than as an authoritative figure.

Fellows also discussed involving students in the process of doing science. For example, Tylor commended Kay:

> There were no instructions given verbally … one of the kids wasn't sure what to do, you were like you need to go and reread the instructions. That's what I loved because I felt like at some point for older kids, they have to learn to figure things out themselves.

By refocusing the students' attention to the written instructions, Kay was giving students agency by encouraging them to navigate the instructions for themselves.

Fellows' feedback also highlighted the importance of teachers being deliberate about questioning and responding to student thinking. As an example, a Fellow suggested: "Maybe have more discussion among the students, like, on the issue of the 'why' factor.' Similarly, Gema encouraged her colleague to focus more on eliciting feedback from students: 'For you to stop and listen to their thinking, maybe to share what they thought.' There were other discussions about teachers taking on an authoritative role, especially as verifiers of science or affirmation of ideas. Even though the Fellows understood that repeating students' responses would benefit students who did not hear or understand what was said, they perceived the practice as the teacher using their power to authenticate and confirm ideas. Stevie noted that Casey repeated student responses: 'There were only one or two responses that you did not repeat word-for-word.' She advised that such practice can 'take away students' sense and make them think that until the teacher utters it, it is not real.' The implication is that when students are conditioned to await the teachers' verification of their peers' ideas, they may not listen to each other and instead listen only to the teacher, taking away their sense of agency. This perceived role of the teacher as the 'verifier' of knowledge was also evident in feedback to Emery: 'While you were asking Question 2, the student said something wrong, and then you said "No, that's not the answer."' In these cases, Casey and Emery's professional identities as science teachers––as the bestower of knowledge to their students––was being challenged by their peers.

Another suggestion for empowering students over their own learning involved appointing them to the role of 'teacher'. Kay suggested that they could 'have the students active in their own education, if you can find something to do like teach the concepts to the other students, then you know they have grasped the concepts.' This suggestion transferred the instructor's role to the students. Under this model, the ownership of learning the content would rest with the student, as they are now responsible for their peers' understanding of the concepts.

Socially constructing science knowledge

Including students in the process of learning science begins with building on their prior knowledge (Rupley & Slough, 2010) and involving them in all phases of scientific experimentation. According to the teachers' feedback, this began with involving students in the planning of experiments. For example, Mack appreciated that Chris did not provide an experiment on cells, but instead asked students, 'What would you like to learn about prokaryotic and eukaryotic cells?' Using this starting-off point, the teacher invited the students to ask questions and determine the direction of the laboratory experiment. This feedback aligns with the emphasis on giving students a chance to voice what they want to learn so that they can engage in authentic learning experiences (e.g. Bevins & Price, 2016). In further commending the teacher, Stevie noted that 'you're getting them to question and that is what we want them to do. The responsibility shouldn't always be on us.'

The open-ended nature of some experiments was evident not just in the problem-posing but also in the preparation of the experiments. Even after they posed questions, the students in Olivia's class were invited to help plan the experiment:

> It was their plan, all I had to do was give them a question (on) how we can observe the phases of the moon in our own classroom so they talked about it, they came up with an idea of a flashlight, the idea of the four balls and so then I just pushed them just a little bit ahead on how we would create a lab here.

Fellows commended their peers on allowing for the co-planning experiments, including students generating lists and collecting materials for the experiment. In describing this 'key component' of co-planning the experiment, Tylor said:

> They had to come up with the list of materials that they needed and then come to me at the supply station to get the materials. So, they had to talk prior to carrying it out. They went home with the list of materials that they needed.

As opposed to prescriptive laboratory experiments that are often cited as not promoting inquiry (Furtak et al., 2012), Fellows embraced the opportunity to make their experiments open-ended, keeping the focus on answering the question rather than on step-by-step procedures.

Fellows seemed to be in agreement about the merits of co-planning laboratory activities with their students, but conceded that sometimes, teacher-led demonstrations were more realistic, given the classroom constraints. In his cool feedback, Cameron suggested that the teacher avoid teacher-centred demonstrations, but that if he needed to, to include student input: 'Could they have made predictions? When a person came up and showed what the object was, they could make a prediction by discussing among themselves then share what they think?' She suggested that students should be given an opportunity 'to do a little more hypothesising before going to the demonstration'. This offers a way in which the teacher can guide students' discussions and construction of knowledge (Darus & Saat, 2014), even during demonstrations.

Students' narrating of science was also noticed in how they reported the results of experiments. Leah noted how in having students report and seek feedback about the experimental results, the teachers were incorporating tenets of inquiry-based science: 'I thought the kids did a good job reporting and giving feedback and giving results while they were doing it. I felt I was looking at little scientists (laughter).' Similarly, Kay commented about the same classroom experiment:

> They were demonstrating that they did understand … and were not going through the motions but were defending their position of what they thought … they were demonstrating that maybe my answer is not right, but here is what I'm thinking based on that. So, if you are able to defend a position, it shows that you have some form of understanding.

Fellows appreciated that this form of debate, especially when it was based on their experimental results, empowered students as members of a scientific community.

Discussion and conclusion

We aimed to understand how teachers described and navigated tensions around change-oriented practices in their teaching. As Fellows watched each other's videos, they noted

areas of strength and areas for improvement relative to their visions for democratic practices in the science classroom. Using the lenses of critical reflection, shared authority, agency, and democratic teaching, we offered a fine-grained analysis of the teachers' efforts and challenges as they attempted to align their practices with these principles.

In exploring the themes that emerged from our data, the issue of the teacher's role became a central focus, with teachers insisting that their roles were shifting from 'knowledge transmitters' to facilitators. Fellows voiced their concerns about power dynamics within the classroom and expressed a need to distribute power to the students. Consistent with the literature, Fellows acknowledged that when teachers exercise complete power over their classrooms, their efforts for reform-oriented science teaching practices become futile (Arnold & Clarke, 2014; Basu & Barton, 2010). Some of the teachers' discussions, however, revealed their reluctance to relinquish their authoritative positions even as they understood the need to empower students in their learning. Issues of not being able to rely on students' understandings, student behaviour, and time constraints were concerns impeding the enactment of their visions for a democratic classroom. Fellows also attributed some of their reluctance to the discrepancy between their teacher education programs and the tenets promoted in the science education standards.

The teachers' discussion about sharing power in the classroom extended beyond the questions of who talked and whose perspectives were considered. The tensions that arose around power in the classroom were often related to the parameters under which the teachers were operating. These parameters included the curriculum, time, school culture, and the teachers' expectations for the science their students were exploring. In many cases, sharing power seemed to go hand in hand with relinquishing control. Despite Fellows' desire to facilitate a student-centred classroom, they still maintained intellectual control of the content by being the 'verifier,' 'knower', 'authority' of science or the ones trying to get students to 'that point' in the discussion. These dilemmas were confounded by the teachers' obligation to the school and curriculum. School events (e.g. unscheduled assemblies) and pacing schedules also served as hindrances to shared authority. Teachers discussed their need to balance their professional identity (as teachers) with their desire to relinquish more control. The debrief sessions allowed them to pose related questions and to challenge one another to consider what an appropriate balance might be.

Although many of these questions remained unresolved, Fellows' suggestions for working within these constraints included physically changing the layout of the classroom, explicitly stating the teachers' expectations for student participation, and involving students in the selection of materials for laboratory experiments. When discussing more significant changes to teacher-led instruction—for example, switching from a demonstration to a laboratory experiment— teachers voiced their concerns. These concerns were related to the disconnect between teachers' visions for science teaching and their actual practice, as revealed by the videos. Our study illuminated some of these conflicts but did not attempt to address them directly. Perhaps further research on how a PD program can support teacher to address these conflicts is warranted.

Our study also illustrates the insights that can emerge when teachers have ownership of their professional development. Their vision of a democratic classroom drove the teachers' discussions and mirrored how teachers engaged in their professional learning. The teachers identified problems of their practice in the videos and drew upon their expertise

to contribute to the conversation, consistent with research-based recommendations for PD (Darling-Hammond et al., 2017). As opposed to programs where an outsider determines the content and direction of the program, our Fellows were central figures in their own professional learning, thus positioned as key players in determining the issues most pertinent to their professional growth (Smith & Lindsay, 2016). In this way, Fellows were called upon to be *professionals* in the *professional* development program, much as they envisioned their students being the *scientists* in the *science* classroom. The collaborative process of critical reflection where teachers, together, identified problems to solve (Fook, 2015) gave them ownership over their professional learning. As they explored possible approaches to addressing these dilemmas, the teachers constructed knowledge together, based on their expertise and a shared vision for science instruction.

Certain characteristics of the PD program enabled the teachers to socially construct knowledge in these ways. Specifically, the program was based on the teachers' classrooms and was content-based, facilitated by the teachers, and held over a prolonged period of time. These characteristics contrast with some other PD programs that rely on outside 'experts' to offer modular or discrete workshops (Darling-Hammond et al., 2017; Smith & Lindsay, 2016). Although certain elements of the debrief sessions were structured (e.g. scheduling of video recording, duration of debrief sessions), the sessions themselves were fluid in that they were facilitated by the teachers (notably in the absence of an outsider or administrator), allowing teachers to identify issues important to them and work to enhance their collective understandings. Although the focus of our study was on illuminating what teachers valued through the analysis of their feedback, a contribution of the study is a description of how PD can enhance teachers' professional learning experience by supporting their collective construction of knowledge.

This research has further implications for the design of PD programs. Whereas the video analyses in our program was not cyclical, PD programs could use a multi-pronged approach. These programs could take advantage of the power of video analyses to have teachers identify needs, suggest strategies, implement these strategies, and then follow up with another round of video analyses on lessons that incorporate these suggested strategies. The iterative nature of this type of program would also be responsive to the needs of PD, including that it be sustained over time, teacher-directed, and based in the classroom (Kennedy, 2016; Tunney & van Es, 2016).

This study might also serve to add a different perspective to other PD programs. Similar to our PD program, lesson studies, for example, are practice-based, centred around student learning, and collaborative in nature (Murata, 2011). Both models put the teacher at the centre of their professional activities, allowing them to draw upon their teaching experiences to understand student learning and adapt their instruction. Whereas this study examined how aspect of power influenced the implementation of reform-based approaches in science classrooms, lesson studies typically examine classroom instruction to develop more effective practices for advancing student learning (Lewis, 2016; Saito, 2012). This study has the potential to add a dimension to professional development structures such as lesson studies, which focus on the content and how students learn the content (Leavy & Hourigan, 2016; Saito, 2012) by highlighting the classroom tensions (such as power struggles) that affect teaching and learning.

Our study aligns with literature that suggests that teachers' discussions of their classroom videos support them in inventing effective ways to improve their teaching and

ultimately impact student achievement (van van Es et al., 2015). Further, our study adds insights into the teachers' role as they attempt to reduce the power differential in a science classroom by drawing on student agency and democratic practices. Finally, research into how teachers incorporate feedback into their teaching practices would extend the conversation on using video analysis as a form of PD. Specifically, the research could focus on teachers' conversations around democratic practices in the classroom and study how those conversations impact classroom instruction.

Statement on Human Research

This research has been approved by Montclair State University's Institutional Review Board (#L-001366).

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