Articulating, Learning, and Enacting Democratic Science Pedagogy

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Abstract

Many stakeholders emphasize the importance of diverse populations' participation in the sciences, though the motivations for this vary. Some reference an economic standpoint by emphasizing the importance of either recruiting more science workers to compete in a global economy, or of individual financial success for people from historically marginalized groups. However, a growing body of researchers and educators has emphasized the importance of increasing representation from historically marginalized communities in science because their exclusion from discussions about science funding, research, and implications has resulted in widespread harm to communities. The goal of this research is to broaden science participation for the purposes of democracy and strong equity. This work expands on the Democratic Science Teaching (DST) framework, articulated by Basu & Calabrese Barton in 2010. While the original work articulated a theory by identifying goals and practices in existing science classrooms, this work explores the possibilities of using DST as a framework for teacher learning.

This dissertation consists of three papers. Paper 1 details the development of an instrument to measure teaching practices aligned with democratic science teaching. The instrument could be used and built on by researchers, teacher educators, and school leaders who wish to use tools to develop democratic accountability in their systems. Paper 2 is a case study exploring how teacher beliefs and actions are activated through interaction with the DST framework. The study follows one novice physics teacher who participated in a DST-aligned professional learning fellowship for one academic year. Paper 3 is a practitioner-facing piece that functions as a starting point for teachers who are interested in developing democratic teaching practices in their own classrooms. The paper outlines the DST framework for teachers, explores how a photo-journal project supported students in making connections between their personal lives and science content, and presents other strategies used by teachers to bolster student voice,

shared authority, and critical science literacy. Altogether, these papers offer understanding of teachers' experiences as they work with the DST framework as learners, and provide tools for science teachers, teacher educators, and other education leaders to develop DST-aligned programming, and more broadly consider democratic and holistic systems of accountability for teachers.

Dedication

I would like to dedicate this dissertation to the many people who have educated me in a variety of ways. To my parents, Sandy, Jesus, and Lisa, who have altogether taught me a unique mixture of skepticism and acceptance, of caution and tolerance, of care and boundaries. To my siblings, Jessica, Vicente, and Joshua, who have been at different times my first classmates and my first “students”. To my many classroom teachers, especially my first-grade teacher Mrs. Cole, whose owl pellet investigations opened a door to science learning. Finally, to my husband Diwei and my children, Eliot and Matilda, who have all provided support, laughs, and inspiration along the way.

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Section 1: Introduction

Science skepticism, misinformation, and misunderstanding are creating significant challenges for the collective health of humanity (Rutjens, van der Linden, & van der Lee, 2021). In popular media, misinformation is given airtime in media along with accurate science in the interest of presenting “both sides" of an issue for political reasons, creating a false perception among the public that issues such as climate change and vaccine efficacy, which in fact have broad consensus in the scientific community, are still in doubt (Struthers, Arnold, Scott & Fleischman, 2021). Unfortunately, scientific literacy has long been treated as a privilege for those who can access it. In schools, which are often among children’s earliest exposure to science as a discipline, science instructional minutes are in fact on the decline, with less time spent on science than on other core subjects (Trygstad et al. 2013; NASEM 2021; Hirst-Bernhardt & Amalsi, 2022). This is exacerbated in schools that serve poor communities and communities of color, where inequitable funding policies limit opportunities to engage in high-quality science learning (NASEM, 2021).

It is tragically unsurprising that these communities then bear the brunt of society’s gaps in science understanding. With climate change as one critical example, those most affected by misinformation and lack of action grounded in science are disproportionately poor and Black and indigenous people of color (BIPOC) (Kalkstein & Smoyer, 1993, Mahe et al, 2013, Maldonado et al, 2013, Thomas et al, 2019). Furthermore, in the US, even though there have been amazing humanitarian advancements that improve the quality of life of many, our track record is marred by abuse and exploitation in the interest of progress and justified by science conducted by primarily white and wealthy people (Green et al, 1997; Seto, 2001). Harding argues that this monolithic form of science has done harm by limiting the beneficiaries of science primarily to those who have traditionally had the privilege of doing it:

> "Because [scientific] research tends to be expensive, the perspectives that tend to prevail in research are those of already advantaged groups that can access funding. Consequently it is their economic, political, and cultural assumptions, intended or not, that tend to shape results of research" (2015, p. 34).

Through this quote, Harding argues that rather than being a truly neutral or objective tool, science is employed in the service of those who use it. Therefore, in order for science to serve all people, rather than a privileged few, it is critical that a truly diverse set of voices guide the path of scientific research and advancement, bringing their particular perspectives and critical awareness of the history of science to course correct. Where historically science has been dominated by the voices of predominantly white, wealthy men, "the standpoint of poor people, of racial and ethnic 'minorities,' of people in other cultures, of women, of sexual minorities, and of disabled people must be elevated in science discourses in order to right the wrongs of history" (Harding, 2015, p.36).

There is some progress in this area. Post-secondary science education and science work is populated by an increasingly diverse field of individuals, although it continues to be done primarily and disproportionately by middle-to-upper class white men (National Science Foundation, 2019). Perhaps in part because STEM career participation is fairly straightforward to measure, much of the research and work around diversifying STEM is grounded in the goal of bringing more diverse workers into the STEM career pipeline (Sass, 2015). Generally, it is true that pathways into STEM careers can be important and uplifting for students from low-income communities and communities of color. These roles can offer both financial stability, social respectability, and a sense of meaning (Blustein et al, 2022; Byars-Winston, 2014; Shoffner & Dockery, 2015). Yet allowing current owners and employers - who continue to come disproportionately from white and wealthy backgrounds - to determine the metrics for a "good"

STEM education will merely produce workers who are trained to support the interests of those same employers, regardless of what community that the employees come from. This would result in indoctrination in the system as it is, rather than empowerment to reshape it. King & Pringle noted this trend and argued that "the impetus to increase the participation of diverse populations in the STEM disciplines has centered around maintaining U.S. global competitiveness and economic prosperity which is a self-serving initiative that lacks sincere moral concern or commitment to the well-being of children of color" (2019, p. 540). Additionally, Blustein & colleagues argued that "individuals without much social and financial capital may experience the push toward STEM careers as an essential means of social and economic mobility and may feel *pressured* to examine these options" (2022). In order to create and sustain meaningful change, science learning has to be grounded in the needs of impacted communities as determined by the members of those communities, not merely by external market forces.

Teaching Diverse Students for Engagement or Disengagement in Science

Individuals tend to decide whether science is something interesting to them or irrelevant to them in school, particularly around the age of middle and early high school (Santrock 2007, Maltese & Tai, 2011; Olitsky & Milne, 2012). As stated earlier, science may be taught rarely if at all in elementary grades. In middle or high school where it is more commonly taught, it is often presented in a way that can be unappealing for students and shows little connection with their lived experiences and community needs. Some researchers have termed this style traditional or "conservative" science teaching and have identified it as a component of the problem of science disengagement (Stroupe, 2014). Science teaching that focuses primarily on memorization of facts, cookbook science labs and students as passive retainers of information is incredibly common, particularly in schools with large low-income and BIPOC populations, as well as incredibly problematic (National Academies of Sciences, Engineering, and Medicine, 2019;

Cherbow, McKinley, McNeill & Lowenhaupt, 2020). Students, especially girls, BIPOC and low income students, report that learning science in this way shows them that they are not welcome, that it is not “for them”, and that even if they wanted to get involved in doing science they would have to reject other components of their identities to do so (Brown, 2006; Hill, McQuillan, Spiegel & Diamond, 2018; Walls, Buck & Akerson (2013). This means that the very voices that Harding (2015) argues could reshape the direction of science in a more just and equitable direction are stifled in many middle and high school classrooms. Furthermore, it misrepresents science as a static body of facts to be learned by individuals, rather than the dynamic and highly social process it is, informed by new questions and new evidence by people in constant communication with one another (Kuhn, 1970).

In 2012, the NRC framework laid out several goals and recommendations for changing science instruction to engage students in “figuring out” rather than “learning about” science (NRC, 2012; Schwarz, Passmore & Reiser, 2017). Notably, the standards emphasize the use of *scientific practices* in the classroom - where students actively engage in the work of doing science in collaboration with one another. Today, the resulting science standards called the Next Generation Science Standards (NGSS) have been adopted and adapted by 44 states. The recommendations were lauded as promising by many scholars, particularly in the area of engaging diverse and systematically disenfranchised students in science. Lee and colleagues emphasized the ways that the shifts required by the standards supported more rigorous learning for emergent multilingual students (2018), while Bang and colleagues noted that the standards’ focus on science practices could “create new opportunities for students from diverse communities to engage meaningfully with science” (2017, p.55). However, some scholars argued that the standards were not explicit enough in requiring educators’ attention to engagement, equity and diversity. Notably, Rodriguez (2015) argued:

> a teacher could have the best preparation in learning theory, content and pedagogy, but if he or she has not been well prepared to be a more culturally inclusive, respectful and responsive teacher, this individual would likely not be able to establish a productive professional relationship with students and their parents. (p.1041)

This suggests that teachers require additional support in culturally inclusive and sustaining practices in order to successfully use those practices. There is rich scholarship around domain-general approaches such as culturally responsive teaching or culturally sustaining pedagogies (Gay, 2002; Ladson-Billings, 1994 & 2014). Yet teachers in the STEM disciplines often find it difficult to integrate them within their own classrooms (Brown, Boda, Lemmi & Monroe, 2019). Underwood and Mensah (2018) argued that teachers needed comprehensive frameworks that explicitly integrate science and cultural responsiveness in order to understand that science and student culture can be synergistic for learning, rather than in competition for precious teaching minutes. Brown and Crippen (2016) furthermore argued that teachers needed explicit support in finding opportunities to enact culturally responsive practices in their classrooms - they needed to see, and practice, this work in their own contexts. Thus, teachers need both theoretical and practical support in order to create classrooms that engage and support culturally diverse learners.

An additional pressure on teachers to teach in ways that are not culturally responsive comes through the accountability system. Despite some shifts in the 2015 Every Student Succeeds Act (ESSA), federal policy still primarily focuses on standardized test results as a marker for school and educator quality (Schneider & Saultz, 2020). And though there is some room for flexibility under ESSA, many state and local leaders default to standardized assessments as the primary measure of quality of schools. (Beyond ESSA 3.0, 2023). The test-driven system has had a notable impact on classroom instruction, perpetuating "teaching to the test" practices that lack both rigor and cultural responsiveness (Jennings & Bearak, 2014, Cochran-Smith et al., 2018). In light of this, there is a growing body of educators and researchers advocating for a broader, more democratic accountability system for schools, teachers & students (Cochran-Smith et al., 2018; Beyond ESSA 3.0, 2023). While federal policy is unlikely to shift in the near future, the Beyond ESSA report puts forth several recommendations for states, districts, and schools to build out an accountability system that provides a more holistic picture of what is happening in schools (2023). Cochran-Smith and colleagues have advocated for a shift to a democratic accountability system, with the goal of "learning environments that enhance students' academic, social, and emotional learning and also prepare them to participate constructively in a complex, diverse, and divided democratic society" (2018, p.195). For science educators and K-12 science education, it would be useful to build programs and tools to build not only understanding and proficiency around culturally responsive, justice-oriented science teaching, but to also find ways to align accountability systems to identify and promote these practices.

Democratic Science Teaching as a Potential Framework to Support Justice in Science Education

One potential framework that could support this theoretical, practical, and policy work is the democratic science pedagogy framework. In 2010, Basu & Calabrese Barton drew from work with students and teachers who identified practices that aligned with literature on democratic pedagogy, but in a specific science context. The researchers then articulated the democratic science pedagogy framework of specific principles that could shape classrooms into spaces that empowered urban minority youth (p. 73). The following year, Calabrese Barton and colleagues renamed this framework as Democratic Science Teaching (DST) and refined it into three principles: student voice, shared and transformational authority, and critical science literacy

(2011). This work notably predates the NRC framework and resulting science standards; however, revisiting it may be productive for teachers who struggle with integrating culturally responsive/sustaining teaching and science because it explicitly ties together science learning and student centered, democratic practices. As stated in the previous section, science teachers often struggle to make connections between their discipline and culturally responsive practices and beginning with a framework that does so by design can remove some barriers for teachers.

The principle of *student voice* is based on the idea that students have a right to free speech in the classroom. In practice, this may result in increasing the space for students to discuss and debate ideas, and by showcasing student work throughout the classroom. Calabrese Barton and colleagues argue that this practice can be transformative for students; a shift from passively receiving information from the teacher to creating and authoring content in the classroom (2011). The DST framework acknowledges that students have lived experiences stemming from their homes and communities that are valuable assets for learning in science classrooms (Basu & Calabrese Barton, 2010). In contrast to traditional classrooms, where all decisions are made by the teacher regarding culture and content, classrooms with *shared and transformational authority* seek to expand student choice. This is the second principle, and it allows students opportunities to make decisions about what and how they learn, how they demonstrate their learning, and about the classroom environment in which learning takes place. Finally, *critical science literacy* (CSL), the last principle, should not be mistaken for functional subject literacy, which concerns mastery in disciplinary knowledge, or *what* students should know. Rigorous subject matter expertise is a component of CSL, but equally important is the investigation of science with a critical lens, where students ask who the discipline has benefitted historically, and how it can be used to address locally based inequities in the world today (Basu et al, 2009). See table 1 below for an overview of the three principles.

Table 1

The Democratic Science Teaching Framework

Democratic Science Pedagogy		
Student Voice	Shared/Transformational Authority	Critical Science Literacy
Students have a right to share their ideas and opinions in the classroom regarding science ideas	Students have a right to work with the teacher to shape how and what they learn	Students have a right to explore science critically, investigating who benefits from science ideas and how science can be used in their own communities

By incorporating democratic practices with a specific science teaching context, this framework has the potential to be useful for science teachers who have thus far struggled to make science teaching more responsive and affirming for students. “Empowering teachers and students in traditionally marginalized urban schools to craft science instruction in ways that feel meaningful and relevant opens doors for students to engage in science and to redress power differentials in their lives” (Basu & Calabrese Barton, 2010). As originally defined, Basu and colleagues drew these principles from teachers’ *pre-existing* ideas and practices. The purpose of the papers in this dissertation is to explore the potential affordances and challenges of the DST framework as the basis for professional learning for teachers as learners and adopters.

Organization of the Dissertation

This dissertation is organized into five sections—an introduction, three papers, and a conclusion—as outlined below.

Section I - Introduction: This current section introduces the dissertation context, the unifying framework of Democratic Science Teaching, and the research questions under study that will shape the three papers.

Section II - Paper 1: The first paper describes the process used to develop a survey to measure teacher-reported shifts in *practices* aligned to the DST *principles*. This paper will address the following research question: **What is the construct validity of an instrument developed to measure teacher implementation of the DST principles?**

While the initial item selection and instrument development was a collaborative effort involving a small research team, I will individually undergo the process of content and construct validation through the use of an expert panel review on the questionnaire and a confirmatory factor analysis on two years of teachers' responses to the pre-survey. This will help to determine the validity of the survey items, and perhaps more importantly, to disqualify items that are not well aligned with the key constructs (Stapleton, 1997), which will be defined by the DST principles of student voice, shared authority, and critical science literacy. This will yield an instrument that can be used in future research to measure teacher practices aligned with the DST with an eye toward expanding democratic accountability systems for teachers.

Section III - Paper 2: In the second paper I will examine a case teacher's experience of learning about the DST and figuring out how it can be used in his own classroom context and explore how his DST learning aligns with the broader shifts in expectations for science educators. This paper will answer the following research questions:

1.What beliefs are activated over a year as a teacher engages with the Democratic Science Teaching framework?

2. How do those beliefs inform the teacher's instructional choices?

Through qualitative analysis of semi-structured interviews, collaborative discussions from professional learning workshops, classroom observations, and teacher-generated artifacts, I will explore how the case teacher uses the DST to identify and address a "problem of practice" over the course of a year. This will serve as an instrumental case study of the development of a new physics teacher - one deep-dive into a specific case to better understand the larger, overarching considerations that may exist for teachers who attempt to develop a democratic science classroom early in their teaching career (Stake & Savolainen, 1995).

Section IV - Paper 3: The third paper is a practitioner article that will briefly outline the DST for an audience of professional high school teachers, describe how one exemplar teacher practically applied the DST framework in her own classroom, and will primarily look at how a student photo journal project could be used to strengthen critical science literacy for students. This paper will address the question: **How can teachers implement the DST in order to bridge the content in the classroom with students' lived experiences?**

Phil Bell emphasized that in the work of advancing research into justice-oriented, equitable science instruction it is critical to develop an infrastructure of actionable, research-grounded resources for teachers, arguing that "we need to…develop shared resources that can inform others, spread these approaches by developing collective understanding, and then adapt tools and practices to new contexts" (2019, p.688). The purpose of this work is to articulate the DST specifically for teachers and provide concrete examples of how it can be employed.

Section V—Conclusion: This concluding section provides a broad discussion that summarizes the findings of the three papers and provides implications for further research, for policy considerations, and for teaching practitioners and teacher learning providers.

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Section II - Paper 1: Development and Validation of an Instrument to Measure Democratic Science Teaching Practices

The major U.S. federal education policy in the past 20 years, No Child Left Behind (NCLB) has emphasized the importance of student achievement on standardized tests (Gay, 2007), although the more recent Every Student Succeeds Act (ESSA) has walked this back to some extent by emphasizing additional measures of quality for schools (Cook-Harvey, Darling-Hammond, Lam, Mercer & Roc, 2016). Perhaps because of this context, the research on measuring teaching practices over the last 20 years has generally been focused on exploring relationships between specific teaching practices and student outcomes on standardized assessments (Fischer et al, 2014; Odom, Stoddard & LaNasa, 2007; Rivkin, Hanushek & Kain, 2005). Despite this general trend, others have called for and developed research in the interest of identifying and measuring teaching practices related to equitable instruction, arguing that the overall accountability system focuses too narrowly on test scores. “Present accountability systems measure only a fraction of what schools seek to do for young people ....[they] both fail to capture the full work of schools and encourage leaders to reduce the mission of public education” (Beyond ESSA 3.0, 2023). Notably, Cochran-Smith and colleagues argued for a shift away from teacher accountability based on high stakes testing and toward “democratic accountability” for teachers:

> “From the perspective of democratic accountability, the goal is preparing teachers who create democratic learning environments that enhance students’ academic, social, and emotional learning and also prepare them to participate constructively in a complex, diverse, and divided democratic society.” (2018, p. 195)

The message from scholars and educators is clear - we have to look at more than just test scores.

Impact of traditional accountability on science teaching and learning

Although researchers, government agencies, and other organizations have called for efforts to diversify the body of students who undertake post-secondary science education and participate in science careers (NASEM, 2021; NSF, 2019), the exclusion from science of persons from marginalized communities often begins as early as middle school. Many of these youth express a feeling of being pushed out of science fields (Regan & DeWitt, 2015; Syed, Azmitia, & Cooper, 2011) as they come to perceive the sciences as "not for them" (Pinkard, Erete, Martin & McKinney de Royston, 2017; Tawfik, Trueman, & Lorz, 2014). Researchers have indicated that widespread, systematic privileging of limited forms of knowledge to those that can be demonstrated on a multiple-choice standardized test, have driven science classrooms toward instruction that is teacher-centered, focused on fact-retention, and low in rigor (Stroupe, 2014). The legacy of accountability driven by standardized tests is inequitable participation in science.

Scholars and educators have articulated frameworks such as culturally responsive or culturally sustaining teaching in order to expand opportunities for students to participate in classrooms (Gay, 2002; Ladson-Billings, 1994 & 2014). Yet, research demonstrates that even teachers with an understanding of culturally responsive teaching struggle when asked to implement those practices in a STEM classroom (Brown, Boda, Lemmi & Monroe, 2019). The literature on professional development for teachers that supports integration of cultural responsiveness within the science context is growing, with many researchers generating theories about design structures, learning frameworks, and implementation strategies that will support this learning (Brown et al, 2019; Brown & Crippen, 2016; Underwood & Mensah, 2018). As this area of research grows, it will be useful to have a body of instruments that can help to identify teaching practices that are aligned with the goal of democratic accountability.

How the present study contributes to expanding ideas of accountability

In the 2023 report Educational Accountability 3.0: Beyond ESSA, several recommendations were put forth to help shape future educational policy around accountability. Two recommendations in particular inform the present study: first, there is a need for a valid and equitable "array of input and output indicators…that better characterize school quality overall"; and second, that accountability systems "provide interpretable and actionable results…more tightly linked to the actual work of teachers in classrooms" (p. 8). The present study details the development of an instrument intended to measure the prevalence of teaching practices aligned with Democratic Science Teaching, or DST. The fruit of this work is twofold - to more clearly articulate the specific teacher actions or practices that align with the theoretical principles of DST, and to be able to measure those practices as another indicator of quality of instruction aligned with the democratic accountability articulated by Cochran-Smith and colleagues. This study will advance the development of an instrument that could be used to measure and report teachers' instructional practices aligned with a democratic science teaching framework, and could be one way to hold teachers accountable not only to teaching discrete content, but also for fostering a classroom environment that values student voice, choice, and critical disciplinary literacy. As such, it will not address all of the areas of need identified by the Beyond ESSA 3.0 report, but will provide one tool for the needed research.

The Democratic Science Teaching framework

Basu & Calabrese Barton drew on democratic pedagogy literature and on their work with teachers and students in science classrooms to articulate a model for "democratic science pedagogy" (2010, p. 72). They worked with teachers and students to define the characteristics of democratic science classrooms, which included student freedom of speech, shared power between teacher and student, valuing of the knowledge students bring from their personal lives into the classroom, and the ability to examine science as a discipline through a critical lens

(2010, p. 85). In 2011, Calabrese Barton and colleagues incorporated additional research and experiences in classrooms to refine a framework for "Democratic Science Teaching" (DST). The framework consists of three "core conceptual tools": student voice, shared and transformational authority, and critical science literacy (2011, p.8).

Student voice "captures the ideas that students' opinions and ideas matter" (2011, p. 8), and that student voice can be interpreted as literal speech, written work, and action both inside the school and in the community. *Shared and transformational authority* is based on "how and why one leverages knowledge and experience towards bringing about social good" (2011, p. 10). This principle contains the assumption that authority is not strictly related to position, but rather that all individuals possess authority and that it becomes transformational when it serves the students' common good. As a result, teachers and students should share authority in making decisions about what is learned, how it is assessed, and the environment in which learning takes place. Finally, *critical science literacy* encompasses rigorous content expertise, critical examination of the historical and current use of science in the world, and the ability to employ science knowledge to affect change in relevant ways. These three principles, student voice, shared authority and critical science literacy, form the constructs to be measured in this instrument.

Review of the Literature

Rather than starting by developing a brand-new instrument, a review of other instruments was conducted to see if viable tools existed to measure democratic science teaching practices. This section will detail the results of that review and how those results led to the development of the instrument under study in this work.

Existing Instruments to Measure Equity-Centered, Culturally Responsive & Constructivist Teaching practices

In 2007, Siwatu developed the Culturally Responsive Teaching Self-Efficacy Scale (CRTSE) to explore pre-service teachers' sense of self-efficacy regarding their ability to implement culturally responsive teaching practices. This was grounded in the idea that teachers' beliefs in their abilities "may predict whether preservice teachers implement these culturally responsive teaching practices once they enter the classroom" (Siwatu, 2007, p.1087). Another example of an instrument where teachers evaluated their own practices was an instrument called the Teaching Equity Enactment Scenario (TEES) scale. Chang and colleagues developed this instrument to measure novice teachers' implementation of "equity-centered teaching practices" (2019). There, teachers rated their own practices in relation to fictional teachers in scenarios that aligned with different facets of equity centered teaching.

Both the CRTSE and TEES scales were scales meant to explore teachers' self-perceptions of their abilities to enact *content area agnostic*, culturally responsive and equitable practices. Taylor, Dawson & Fraser developed an instrument intended to be used specifically in STEM education settings. The Constructivist Learning Environment Survey was developed with the intention of enabling "teacher-researchers to monitor their development of constructivist approaches to teaching school science and mathematics" (1995, p.2). The instrument could be used by teachers to survey their own students about the frequency of constructivist practices in the classroom. Informed by elements of radical constructivist theory (von Glasersfeld, 1991) and critical social theory (Gottlieb, 1981), Taylor, Dawson & Fraser identified five dimensions of a constructivist learning environment: personal relevance to the students, negotiation between students, negotiation with the teacher, shared control with the teacher, and "critical voice", which is described as the teacher's accountability to students. The dimensions in this instrument share many parallels with democratic science teaching. Notably, "student negotiation" and "critical voice" both align with the DST principle of "student voice", "shared control" with shared/transformational authority, and “personal relevance” with some components of “critical science literacy”.

In short, I found a number of surveys that contained elements of practices aligned with the DST framework, but no single instrument really did what was necessary for this project - to allow teachers to report their specific teaching practices organized by DST principles. In my efforts to find a scale that fully reflected the DST principles & practices, I realized that it would be necessary to draw from multiple sources and make amendments to items. The Instrument Development section will outline in more detail how I drew particularly from the CLES and CRTSE scales in order to address all of the dimensions of democratic science teaching in the instrument, which we can call the Democratic Science Practices Assessment, or DSPA.

Method

Participants and context of administration

The DSPA was initially developed for use in a professional learning program developed to introduce and support STEM educators in the Democratic Science Teaching framework. Ultimately, the internal program goal for the instrument is to be able to measure changes in teacher practices from the beginning of the school year to the end of the school year, during which the teachers would participate in the professional learning fellowship. As such, about half of the participants in this study were teachers who had opted into the teaching fellowship. Additional teachers were recruited to take the DSPA for future use as a comparison group. They were recruited using a snowball recruitment technique - teachers who had been accepted into the fellowship recruited other STEM teaching colleagues from their schools. The fellowship teachers were asked to provide the survey link to three colleagues. In the end each fellowship teacher was able to recruit at least one other colleague. The responses from all of the teachers from two cohorts (2018-2019 and 2019-2020) of the professional learning program, and their recruited colleagues, were involved in this analysis. Background information on the group of teachers is available in Table 1.

Table 1
Teachers' Background for Confirmatory Factor Analysis (N=126)

Grade Level Taught		Gender		Race/Ethnicity[1]	
Elementary	21	Male	32	Asian/Pacific Islander	16
Middle	39	Female	89	Black	18
High	63	Non-binary	5	Hispanic/Latinx	5
Multiple	3			White	64
				Multiple	5
				Undisclosed	2

[1] Additional identifiers were available, including Cape Verdean and Caribbean

For this study, as the purpose is to determine the validity and reliability of the DSPA, I used the responses issued at the beginning of the school year for all teachers. At this stage, all teachers would have a similar, relatively superficial knowledge of the Democratic Science Teaching framework. The DSPA was administered online, using Qualtrics, via a survey link. All teachers provided informed consent prior to going forward with the survey, which took about 15-20 minutes for each teacher to complete.

Instrument Design

Several design considerations were taken in order to address the identified areas of need around valid, reliable instruments that are aligned with a vision of democratic accountability for teachers (Cochran-Smith, et al 2018). The DSPA integrates a Democratic Science Teaching framework along with design features aligned with literature on the development of classroom practice assessments.

Classroom practice assessment design

Although the DSPA was initially designed to be used internally in a particular program, the research team worked to develop an instrument that could be usable by other programs interested in exploring democratically aligned teaching practices. As such, we attempted to design the DSPA in accordance with the teaching practice assessment literature. Three primary design features were considered in order to develop the measure under study, as articulated by Cabrera, Colbeck & Terenzini (2001):

1. The instrument should measure easily describable, observable behaviors.
2. There should be a group of behavioral indicators associated with each construct that are determined to be reliable and valid.
3. The data or information from the instrument should be meaningful to the users.

In the initial work to develop the DSPA, the research team sought to determine if a suitable instrument already existed. This led to the identification of the CLES and CRTSE instruments described in the literature review as starting points.

The CLES survey. The CLES instrument was developed by Taylor, Dawson, and Fraser (1995), in order to monitor *students'* perceptions of "critical constructivist" practices in STEM classrooms. The wording of items on the original scale is aimed at understanding students' experiences in the classroom, for example, students indicate how often on a scale from 1 (Almost Never) to 5 (Almost Always) they "speak up for their rights" or "help the teacher decide which activities to do". Our research team modified this survey for teachers in order to determine their perception of these critical constructivist practices. Using the same scale, we asked how often in their classes "students speak up for their rights" or "students help [the teacher] decide which activities to do."

While the CLES instrument was not designed specifically to measure Democratic science teaching practices, or even to be used with teachers, the research team, in consultation with the

EST fellowship leadership team, decided that the instrument items mapped onto some of the EST principles. The dimensions of critical constructivism as defined by Taylor, Dawson, and Fraser include student critical voice, shared control between teachers and students, student opportunity for negotiation of ideas, and personal relevance to students of the class content (1995) - all of which seemed closely aligned with the principles of student voice, shared authority, and some aspects of critical science literacy. We selected 17 items from the 35-item scale that best matched practices described in the DST framework (Basu, Calabrese Barton, & Tan, 2012). See table 2 for examples.

Table 2
Sample Survey Items by DST Principle[1]

DST Principle	Modified Wording	Original Wording
Student Voice	Over the course of the year in my classroom, students express their opinions. Over the course of the year in my classroom, students explain their ideas about what they have learned with each other.	In my science class, it's OK to express my opinion.[2] I explain my ideas about what I have learned with other students.[2]
Shared Authority	Over the course of the year in my classroom, my students help me decide how to evaluate how well they are learning. Over the course of the year in my classroom, I design instruction based upon my students' interests.	I help my teacher evaluate how well I am learning.[2] I help the teacher to decide which activities I do.[2]
Critical Science Literacy	Over the course of the year in my classroom, I use my students' cultural background to help make learning meaningful. Over the course of the year in my classroom, students learn about how science or math can be used to solve problems in their community.	I am able to use my students' cultural background to help make learning meaningful.[3] I learn how science can be part of my out-of-school life.[2]

[1] Response options were a Likert scale format, with 5 being "Almost always" and 1 being "Almost never".
[2] Items adapted from the CLES instrument.
[3] Items adapted from the CRTSE instrument

The CRTSE survey. While the CLES instrument mapped on to several components of Democratic Science Teaching practices, it did not adequately measure one component of critical science literacy - whether teachers reported building connections between science content and students' localized, personal, and culturally contextualized lives. Thus, the research team included 4 items from the Culturally Responsive Teaching Self-Efficacy (CRTSE) scale that address building these connections. This instrument was originally designed to measure pre-service teachers' beliefs in their abilities to enact culturally responsive practices (Siwatu, 2007). Siwatu drew from a wide body of literature on culturally responsive and culturally relevant pedagogies to design the instrument, which phrased questions such as "*I am able to* implement strategies to minimize the effects of the mismatch between my students' home culture and the school culture" [emphasis added] (2007, p. 1093). The key difference in our survey is in the prefix, where the above item would be changed to "*Over the course of the year in my classroom, I* implement strategies to minimize the effects of the mismatch between my students' home culture and the school culture." Like the CRTSE survey, the items on our instrument were presented in a 5-point Likert scale, with 1 representing "Almost Never" engaging in culturally responsive practices and 5 representing "Almost Always" doing so. Some examples are provided in Table 2.

The DSPA was designed in the context of a professional learning program and was intended to ultimately be used to determine whether teacher practices changes would take place as a result of their participation. Therefore, in order to determine "meaningfulness" to the user, a first version of the survey was reviewed by the professional learning facilitator team. Several items were modified as a result of their feedback. Through this initial process of identifying existing surveys, adapting and modifying their language, and presenting them to the facilitator team for review, we sought to address two of the principles for assessment design - observable actions & meaningfulness to the user (Cabrera, Colbeck & Terenzini, 2001).

Small-scale pilot test.

Multiple steps were taken to ensure content validity. After review by the facilitator team, the survey was administered to one cohort of K-12 teachers from the 2017-2018 program year (N=54), and then analyzed with an exploratory factor analysis. This aided in the identification of survey items that did not load onto common factors with other items, which were eliminated. Using Eigenvalues, the exploratory factor analysis identified three underlying factors onto which the remaining items loaded, which was promising in terms of aligning the instrument with the three principles of the DST. The survey then went through a review by an expert panel and a confirmatory factor analysis.

Expert review.

Once an initial set of items was developed for each construct, a panel of five experts in the area of Democratic Science Teaching were asked to review the items on a form developed using Lawshe's content validity ratio (1975). Each expert had at least five years of experience in a) the original development of the DST framework, b) in supporting teachers in learning the framework or c) both of these areas. The experts identified each item as "aligned", "needs revision", or "not aligned" with the associated DST principle. They then rated each item as either "necessary", "probably necessary", or "not necessary" to define the principle. This provided two content validity ratios (CVRs) for each item. The formula utilized for calculating each ratio was $CVR= (n_e -N/2)/(N/2)$ where n_e either indicates the number of experts that rated the item as "aligned" or "necessary", and N indicates the total number of experts on the panel. According to Ayre and Scally (2018), a panel of 5 experts suggests that all of the voting experts must rate the item as “necessary” and “aligned” in order for it to meet the cutoff value - or that the CVR would have to equal 1. Items that were found “not aligned” and/or “not necessary” were eliminated, while for items that were identified as necessary or probably necessary but needing revision, the experts were asked for suggestions for revisions. As the revision suggestions were relatively straightforward, a second review was not deemed necessary. Once this was done, the content validity index or CVI was calculated to determine the content validity of the instrument as a whole. With revisions made, the CVI = 1.

Data analysis.

As previously stated, the goal was to develop a valid instrument to measure teaching practices aligned with the constructs of student voice, shared and transformational authority, and critical science literacy - the three pillars of the Democratic Science Teaching framework. To explore the construct validity of the model, I performed factor analysis using Stata version 16.0.

I performed confirmatory factor analysis on the variance-covariance matrix of all of the items in the DSPA, first using a 3-factor model to explore the validity of the instrument in measuring three distinct DST principles. I also explored a 1-factor model and a 5-factor model. The 1-factor model represents the hypothesis that the DST framework itself is the underlying factor, and the 5-factor model that the individual sub-scales (critical voice, shared control, student opportunity for negotiation, and personal relevance from the CLES, and cultural responsiveness from the CRTSE) were themselves the underlying factors. I then evaluated the goodness of fit of the three models. I used maximum likelihood (ML) as an estimator and applied the following indices to determine the appropriateness of the fit: the Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square residual (SRMR), with values ≤ 0.05 reflecting a close fit, and ≤ 0.08 a satisfactory fit (Hu and Bentler, 1999; Kline, 2011), and CFI, with values ≥ 0.95 indicating close fit, and values ≥ 0.90 indicating acceptable fit (Bentler, 2007). The chi square/degrees of freedom test was used rather than the chi squared test in order to reduce sensitivity to sample size, with $\chi2/(df) < 3.0$ representing a good fit (Kline, 2005).

Results

Descriptive Statistics

The means, standard deviations, and pairwise correlations of each item are presented in Table 3. Generally, teachers reported higher practices identified as aligned with student voice and critical science literacy than they did practices aligned with shared & transformational authority. This is interesting as the program leaders sometimes presented critical science literacy as the more challenging principle to implement. Overall, items tended to be positively correlated with one another, though these correlations were not always statistically significant. Table 3 also presents the reliability of the items, within their original subscales from the CLES and CRTSE measures and when treated as the three DST principles of student voice, shared authority. When treated as the original 5 subscales, the reliability ranged from 0.65 to 0.90. When treated as the three DST scales, the reliability ranged from 0.80 to 0.88.

Table 3: Summary of means, standard deviations, and correlations.

DST Principle	Original Subscale	Items	CV1	CV3	SN1	SN2	SN3	SC1	SC2	SC3	SC4	CR1	CR2	CR3	PR1	PR2	PR3	PR4
Student Voice	Critical Voice	CV1	1															
		CV3	0.49**	1														
	Student Negotiation	SN1	0.31**	0.25*	1													
		SN2	0.35**	0.35**	0.67**	1												
		SN3	0.30**	0.29**	0.70**	0.74**	1											
Shared Authority	Shared Control	SC1	0.31**	0.47**	0.30**	0.29**	0.22*	1										
		SC2	0.29**	0.32**	0.25*	0.25*	0.25*	0.61**	1									
		SC3	0.29**	0.30**	0.26*	0.26*	0.20*	0.48**	0.59**	1								
		SC4	0.33**	0.32**	0.25*	0.27*	0.22*	0.63**	0.68**	0.69**	1							
Critical Science Literacy	CRTSE	CR1	0.33**	0.29**	0.23*	0.29**	0.23**	0.45**	0.32**	0.18*	0.25*	1						
		CR2	0.29**	0.26*	0.16	0.13	0.13	0.47**	0.25**	0.15	0.26*	0.52**	1					
		CR3	0.27**	0.41**	0.20*	0.21*	0.22**	0.43**	0.35**	0.23*	0.27*	0.54**	0.62**	1				
	Personal Relevance	PR1	0.28**	0.23*	0.23**	0.26*	0.22**	0.34**	0.30**	0.16	0.27*	0.37**	0.25*	0.30**	1			
		PR2	0.28**	0.29**	0.27**	0.23*	0.18*	0.51**	0.42**	0.28*	0.34**	0.51**	0.30**	0.39**	0.61**	1		
		PR3	0.31**	0.24*	0.33**	0.33**	0.26**	0.47**	0.44**	0.32**	0.45**	0.36**	0.30**	0.37**	0.65**	0.73**	1	
		PR4	0.36**	0.31**	0.36**	0.33**	0.24**	0.52**	0.41**	0.33**	0.40**	0.52**	0.37**	0.40**	0.60**	0.80**	0.77**	1
Descriptive Statistics	Mean		4.12	3.47	3.80	3.76	3.73	2.72	2.60	2.83	2.71	3.39	3.43	3.71	3.65	3.16	3.37	2.97
	Standard deviation		0.72	0.90	0.86	0.89	0.92	1.01	1.19	1.12	1.09	0.97	1.00	0.92	0.85	1.03	1.03	1.11

alpha (subscale)	0.65	0.87	0.85	0.79	0.90
alpha (proposed DST principle)	(Stdnt. Voice) 0.80		(Sh. Auth) 0.85	(CSL) 0.88	

Confirmatory Factor Analysis

Table 4 displays the fit indices for the models. All standardized factor loadings for the 5-factor model, which provided the best fit overall, were in the large range (0.68-0.91) and were statistically significant- ($p<0.01$).

Table 4
Summary of fit statistics for the factor model of DST

	$\chi 2$(df)	CFI	SRMR	RMSEA (90% CI)	$\Delta\chi 2$	ΔCFI	ΔSRMR	ΔRMSEA
5-factor interdependent* model: Critical Voice, Student Negotiation, Shared Control, Cultural Responsive, Personal Relevance	134.728(94)	0.962	0.057	0.059 (0.034-0.080)	-	-	-	-
3-factor interdependent* model: Student Voice, Shared Authority, Critical Science Literacy	242.165(101)	0.868	0.113	0.106 (0.089-0.123)	107.437(7)	-0.094	0.056	0.047
1-factor model: DST	510.02(104)	0.621	0.124	0.177 (0.162-0.192)	375.292(10)	-0.341	0.067	0.120

Note. $\chi 2$ = chi-square; RMSEA = root mean squared error of approximation; SRMR = standardized root mean square residual; CFI = Comparative fit index.
*Independent models were also tested with both 3 and 5 factors; these models did not converge

1-factor and 3-factor models

A 1-factor model was specified to represent the situation where one underlying construct, called “Democratic Science Teaching”, best explained the relationship between these items. The fit statistics overwhelmingly indicated that this model was a poor fit to the data, with $\chi 2/(df)>3.0$, RMSEA > 0.06, SRMR > 0.05, and CFI<0.95. The 3-factor correlated model represented the case where the items were best represented by the three DST principles: student voice, shared authority, and critical science literacy, which was the initial intention of the survey design.

However, although the 3-factor model showed a better fit to the data in some measures ($\chi2/(df) < 3.0$), overall, the fit statistics indicated a poor fit (RMSEA > 0.06, SRMR> 0.05, CFI < 0.95).

5-factor model

Finally, the 5-factor correlated model was tested. In this model, the items were each loaded onto factors represented by the original sub-scales that they were drawn from (Critical Voice, Student Negotiation, Shared Control, Cultural Responsiveness, and Personal Relevance), with each subscale identified as being correlated with each other. The fit statistics for this model all indicated a good ($\chi2/(df) < 3.0$, CFI>0.962, SRMR > 0.05) to acceptable (RMSEA = 0.059) fit. All factor loadings were statistically significant ($p<0.001$). The standardized factor loadings ranged between 0.68 to 0.91, which can be considered large overall. For example, an increase of one standard deviation in shared control would result in a .76 standard deviation increase in shared authority question 2, student input in content to learn. The factor structure with standardized loadings appears in Figure 1. Tables that show how each item maps onto the intended DST principles, and how the items mapped onto the final 5-factor model, are available in the appendix.

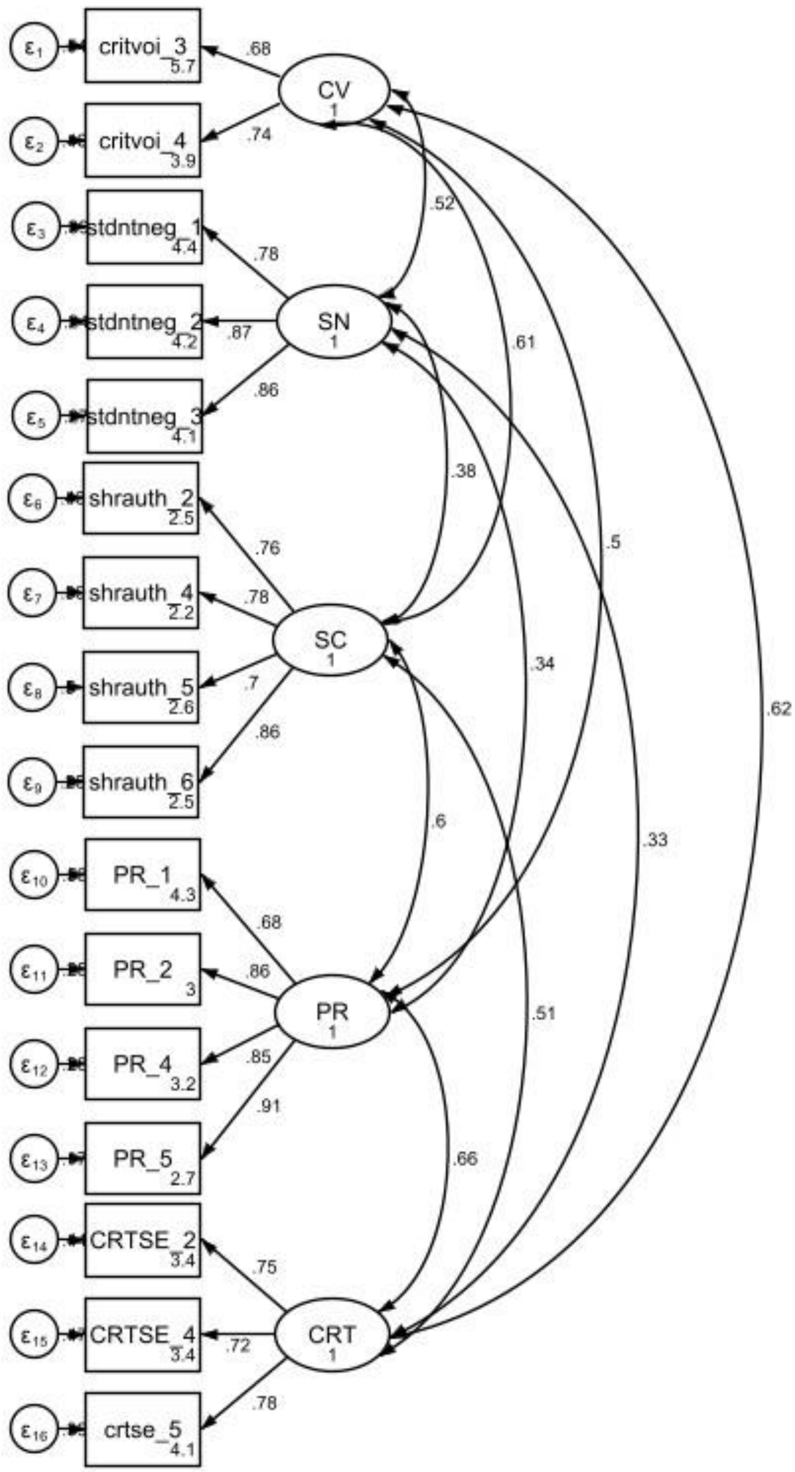

Figure 1: 5-factor interdependent model with standardized factor loadings

Discussion

These results indicate that the three overarching ideas of student voice, shared authority, and critical science literacy as conceived and operationalized for the DSPA do not actually lend themselves to being easily measured as three underlying constructs. Rather, the idea of "student voice" is broken down into the more precise constructs of critical voice, representing student feedback to the teacher, and student negotiation, representing student discussion with one another. Similarly, the idea of "critical science literacy" is broken down into the more precise constructs of "cultural responsiveness" and "relevance to students". Given that the items were taken from five separate sub-scales, these results are not surprising. Still, the model does suggest interdependence between the underlying constructs as they show correlations and covariances with each other. There is likely a relationship between the underlying constructs, and the DSPA, as a whole, may still be useful in measuring practices that are aligned with the DST framework, particularly as indicated by the expert panel review of the items, and the inclusion of the program facilitators in the design of the instrument.

It is important to note that while the sample size for this study met minimum requirements, a large sample is preferable to conduct confirmatory factor analysis. Further exploration of the factor structure of this instrument may be merited with large and diverse groups of educators in order to make broad claims about the constructs that inform "democratic science teaching". Additionally, the framework itself has gone through reconceptualization over time. In early research, it was proposed that DST consisted of up to six principles - student freedom of speech, student funds of knowledge in the curriculum, shared teacher-student power through voice, neutrality through choice, construction of community, and critical science agency (Basu & Calabrese Barton, 2010). The current "three-principle" model was articulated after additional work with and input from teachers and students. Calabrese Barton and colleagues present student voice, shared authority, and critical science literacy as "three core conceptual tools that help to frame ways of thinking and being in classrooms that work towards a more just world", also acknowledging that they may be "taken up in different ways" across classroom contexts (Calabrese Barton et al, 2011, p. 7). It may be possible that for teachers learning the framework, thinking of DST in terms of three overarching principles is a practical and manageable approach, while for measurement and research purposes, it may be useful to tease out more specific constructs that can be otherwise bucketed within the three-principle model. Or practitioners may find a model with more pillars useful. Either way, further research and work with a broader group of teachers could be helpful to either expand, refine, or adjust the principles of democratic science teaching for the dual purposes of 1) introducing the framework to other teachers and 2) accurate and informative measurement of DST-related practices.

Further complicating this work is the unique nature of individual classrooms and their local cultural contexts. By definition, a democratic classroom represents the voices of those that inhabit it. Therefore, while this instrument could be a starting place for educators or professional learning providers to evaluate specific teaching practices, it is important that student voices and input shape the ultimate decisions about what counts as democratic practice in a classroom. As stated by Basu & Calabrese Barton, "each set of science educators that pursues democratic science pedagogy should consider existing models for this practice and then work with teachers and students to envision this pedagogy in the local school context" (2010, p. 84). The DSPA as presented could provide a base model for school leaders and/or teacher educators to use to further tailor to their context based on the feedback of students, teachers, and other important stakeholders in their local communities. Practical suggestions for including other stakeholders in this process this can be found in the following section.

Implications

For this instrument and its development

Initial steps for further research on this instrument could include expanding the sample size for the instrument as-is, and adding, editing, or refining the items in the instrument. With a sample size of 126, this study meets minimum guidelines for a confirmatory factor analysis. However, CFA is sensitive to sample size, and it would be useful to gather more data across multiple cohorts of science teachers in order to further support the reliability of the 5-factor model. However, due to the nature of the instrument being used in a variety of contexts, it might also be useful to conduct additional expert panel and/or user reviews to determine if there are areas of the DST framework that could be better specified by modifying or adding items. Further iterative rounds of review and factor analysis are recommended.

For teacher educators

For researchers, leaders, and educators who would be interested in providing programming or professional learning around democratic science teaching practices, these results present some considerations for program design. To start, it is possible that the overarching three democratic science teaching principles should be further broken down for the purposes of supporting teachers' understanding and identifying concrete objectives for teachers. For example, the principle of "student voice" was better modeled in the DSPA as two components - student voice as feedback to the teacher (for example, students expressing an opinion to the teacher) and students' voices in interaction with one another (students discussing science ideas). While "student voice" broadly refers to students being able to express their voice, opinions, and ideas in the classroom, particularly as they pertain to science content and learning, "student to student" interactions require different skills and present different challenges to a teacher than "student to teacher" interactions. Teachers striving to support rich dialogue between students in science classrooms particularly might lean on the science and engineering practices of argumentation based on evidence, constructing explanations, and/or communicating scientific information (to peers). They would likely benefit from tools or protocols meant to get students engaging in rich conversations facilitated by or even independent of the teacher. These are qualitatively different than situations where teachers would solicit direct feedback or input from students on their classroom environment or learning experiences. Soliciting student to teacher voice could be done through surveys and interviews, or potentially through instructional routines like driving question boards where students articulate questions they'd like to investigate in a particular science unit. Although both situations allow for students to "express voice", the routines, challenges, and strategies would look different for each. It would be useful to further investigate optimal ways of introducing and conceptualizing the DST with teachers.

For teacher accountability research

As part of the greater work of developing tools aligned with the vision of democratic accountability, this study presents but a small step. Notably, to really assess the democratic merits of classrooms, community members, and particularly students' voices must also be present in the evaluation (Beyond ESSA 3.0, 2023). This could be done in two ways - first, students and other relevant community stakeholders could have a say in the important constructs that the survey would measure about teaching practices. Emdin has emphasized the importance of the use of "cogens", particularly in urban classrooms, for students and teachers to discuss their experiences of the classroom on equal footing, and this format could be used to adjust a tool like the DSPA to reflect classroom practices that the students find important for fostering a democratic learning environment (2008, p.774). Ishimaru emphasizes the importance of "approaching parents and communities as…vital collaborators and leaders in efforts to transform our schools and broader educational systems toward educational justice (2020, p.2). Families could be invited to provide feedback on recommended classroom practices that would empower students in ways that respond to the values of the local community. It would be useful to research how the inclusion of these different stakeholders in developing accountability measures for teacher practices influences accountability and the overall values for local education contexts.

Second, students' perspectives on what is happening in the classroom must be taken into account along with the teachers' perspectives. A truly holistic accountability system, as this study hopes to contribute to, will examine students experiences as well as teachers about "how" learning is happening. This way, students' voices can provide additional information and context about what is happening in classrooms alongside the results of more content-driven assessments. For example, the CLES instrument that provided some of the source material for the DSPA tool was originally a survey intended to measure students' experiences of teachers' practices in the classroom. A survey that mirrors the DSPA, but rather measures students' experiences, would provide checks and balances on the teacher's perspective of what is happening in the class. Further research into the impact of authentic student feedback, as part of a holistic and democratic accountability system, would be useful.

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Paper 1 Appendix A: Teacher Survey

Intro
Thank you for taking the time to complete this survey. There are no right or wrong answers. Please answer honestly. Your feedback is much appreciated!

Background questions

1. What is your first and last name? *(Textbox)*
2. Where do you teach?
    a. Massachusetts
    b. New York
3. What grade(s) do you teach? *(allow them to select more than one grade level)*
    a. Options: grades K-12
4. What subject do you teach? *(allow them to select more than one subject)*
    a. Math
    b. Science
    c. Computer Science
    d. Other *(fill in textbox)*
5. Are you a current or past member of the Sci-Ed Innovators Fellowship Program? *(Use this Q to direct respondents to the fellow or nonfellow survey)*
    a. Yes
    b. No

If they answered "yes" to #5, they will see this question:

6. During which schoolyear were you a member of the Sci-Ed Fellowship?
    a. (Year) - (Year) *(*can we have two drop downs with years for them to fill this in?)*

Prompt: Over the course of the year in my classroom...

Critical voice scale (student voice: student-teacher interaction)

Critical voice scale (student voice) (CLES scale; Taylor, Dawson & Fraser, 1995)	**Almost never**	**Rarely**	**Sometimes**	**Often**	**Almost always**
1. ... students ask me "why do we have to learn this?"	**1**	**2**	**3**	**4**	**5**
2. ... students express their opinions.	**1**	**2**	**3**	**4**	**5**
3. ... students speak up for their rights.	**1**	**2**	**3**	**4**	**5**

Prompt: Over the course of the year in my classroom…

Shared control scale (shared authority with teacher)

Shared control scale (shared authority) (CLES scale; Taylor, Dawson & Fraser, 1995)	**Almost never**	**Rarely**	**Sometimes**	**Often**	**Almost always**
4. ...my students give input into what they are going to learn.	**1**	**2**	**3**	**4**	**5**
5. ...my students help me decide how to evaluate how well they are learning.	**1**	**2**	**3**	**4**	**5**
6. ...my students help me decide how much time they spend on activities.	**1**	**2**	**3**	**4**	**5**
7. ...my students help me to decide which activities they do.	**1**	**2**	**3**	**4**	**5**

Prompt: Over the course of the year in my classroom…

Culturally Responsive Teaching Self-Efficacy (CRTSE) Scale (embracing students' funds of knowledge; authority of experience)

Culturally Responsive Teaching Self-Efficacy (funds of knowledge) (CRTSE scale; Siwatu, 2006)	**Almost never**	**Rarely**	**Sometimes**	**Often**	**Almost always**
8. I implement strategies to minimize the effects of the mismatch between my students' home culture and the school culture.	**1**	**2**	**3**	**4**	**5**
9. I revise instructional material to include a better representation of cultural groups.	**1**	**2**	**3**	**4**	**5**
10. I use examples that are familiar to students from diverse cultural backgrounds.	**1**	**2**	**3**	**4**	**5**

Prompt: Over the course of the year in my classroom…

Student negotiation scale (student voice: student-student interaction; shared authority with students)

Student negotiation scale (student voice) (CLES scale; Taylor, Dawson & Fraser, 1995)	**Almost never**	**Rarely**	**Sometimes**	**Often**	**Almost always**
11. ...students talk with each other about ideas related to what they are learning.	**1**	**2**	**3**	**4**	**5**
12. ...students talk to each other about how to solve problems.	**1**	**2**	**3**	**4**	**5**
13. ...students explain their ideas about what they have learned with each other.	**1**	**2**	**3**	**4**	**5**

Personal relevance scale (1. critical science literacy - application of science to personally significant problems/questions; equity/power lens)

Prompt: Over the course of the year in my classroom, students learn about how science or math.….

Personal relevance (critical science literacy) (CLES scale; Taylor, Dawson & Fraser, 1995)	**Almost never**	**Rarely**	**Sometimes**	**Often**	**Almost always**
14. can be used in their out-of-school life.	**1**	**2**	**3**	**4**	**5**
15. can make the world more fair.	**1**	**2**	**3**	**4**	**5**
16. can be used to solve problems in their community.	**1**	**2**	**3**	**4**	**5**
17. can address issues of inequality.	**1**	**2**	**3**	**4**	**5**

Prompt: The following statements apply to **your school** context.

School Community (Connectedness scale; Rovai, 2002)	**Strongly disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly agree**
18. I feel that STEM teachers at my school care about each other.	**1**	**2**	**3**	**4**	**5**
19. I feel isolated as a teacher at my school. (R)	**1**	**2**	**3**	**4**	**5**

20. I trust other teachers at my school.	**1**	**2**	**3**	**4**	**5**
21. I feel that other teachers at my school depend on me.	**1**	**2**	**3**	**4**	**5**
22. I feel confident that other teachers at my school will support me.	**1**	**2**	**3**	**4**	**5**
23. I share what I learn in school or district PD to support colleagues at my school.	**1**	**2**	**3**	**4**	**5**
24. In the school or district PD that I participate in, I feel supported by other teachers.	**1**	**2**	**3**	**4**	**5**
25. In the school or district PD that I participate in, I feel connected to other teachers.	**1**	**2**	**3**	**4**	**5**

Tell us a bit more about yourself and the environment in which you teach!

1. What, if any, school-related activities do you participate in outside of your classroom (e.g., coaching, mentoring, grade-team leader, dept. head, club adviser, etc.)?
    a. Textbox
2. How many years have you been teaching?
    a. 0-2
    b. 3-5
    c. 6-8
    d. 9-11
    e. 12+

3. How many more years do you see yourself teaching?
    a. 0-1
    b. 2-3
    c. 4-5
    d. 5-10
    e. 10+

4. How much administrative support (e.g., assistant principal, principal, STEM coordinator, superintendent, etc.) would you say you have as a teacher?
    a. Scale 1-5 (1= no support; 5= A great deal of support)

5. How much peer support (e.g., other teachers in your school) would you say you have as a teacher?
    a. Scale 1-5 (1= no support; 5= A great deal of support)

6. How many hours of school or district PD do you participate in each year? *(Only in Fellow survey: "PD that is not part of the Sci-Ed Fellowship program")*
    a. 0-5
    b. 6-10

    c. 11-15
    d. 16+

7. How useful is the school or district PD you participate in to your role as a teacher and your classroom? *(Only in Fellow survey: "PD that is not part of the Sci-Ed Fellowship program")*
    a. Scale 1-5 (1= not useful at all; 5 = extremely useful)

8. How would you rate yourself as a leader?
    a. Scale 1-5 (1= no leadership skills; 5 =A great deal of leadership skills)

9. Which of the following describe the majority of students you teach?
    a. Underprivileged students
    b. Middle class students
    c. Students who primarily speak a language other than English at home
    d. Students who are first generation Americans
    e. ESL students
    f. Students of color

10. What gender do you identify with?
    a. Female (textbox for comments)
    b. Male (textbox for comments)
    c. Non-binary (textbox for comments)

11. What is your race/ethnicity? *(Check all that apply)*
    a. Asian, Black, Cape Verdean, Caribbean, Hispanic/Latinx, Native American, Pacific Islander, White, Other (textbox for comments)

Paper 1 Appendix B: Construct Map for Democratic Science Practices Assessment (DSPA).

This construct map represents the Democratic Science Teaching principles as articulated by Calabrese Barton, Basu and Tan (2011) and the underlying constructs that were identified as the best fit model to teachers' responses on the DSPA instrument. The table is organized first by DST principle, and by the underlying constructs that were identified as composing each principle. Then language from each item is organized by how frequently teachers in the study reported using the practice described. This organization suggests that practices aligned with "student to teacher voice" are most common, and perhaps the easiest for teachers to do, while practices aligned with "shared authority" or true shared negotiation between teacher and student are the least common, and perhaps the most difficult for teachers to do. This organization could inform future program design around the DST, where it may be useful to embed more supports for teachers to practice shared authority with students.

Democratic Science Teaching			
Democratic Science Teaching Principle **(Identified Underlying Construct)**	**More Frequently Used (mean > 3.56)**	**Somewhat Frequently Used (3.56<mean>3.00)**	**Least Frequently Used (mean<3.00)**
Student Voice **(Student to student communication)**	Students talk with each other about ideas related to what they are learning.	Students talk to each other about how to solve problems. Students explain their ideas about what they have learned with each other.	
Student Voice **(Student to teacher feedback)**	Students ask me "why do I have to learn this?" Students express their opinions. Students speak up for their rights.		
Shared Authority **(Shared Negotiation between student and teacher)**			Students help me decide how to evaluate how well they are learning. Students help me to decide which activities they do.

			Students give input into what they are going to learn. Students help me decide how much time they spend on activities.
Critical Science Literacy **(Teacher design with cultural responsiveness to students in mind)**	I use examples that are familiar to students from diverse cultural backgrounds.	I revise instructional material to include a better representation of cultural groups.	I implement strategies to minimize the effects of the mismatch between my students' home culture and the school culture.
Critical Science Literacy **(Teacher design with relevance to students in mind)**	Students learn about how science can be used in their out of school life.	Students learn about how science can make the world more fair. Students learn about how science can be used to solve problems in their community.	Students learn about how science can address issues of inequality.

Section III: Paper #2 - A Case of Teacher Learning About Democratic Science Teaching
Introduction

Despite some promising shifts in recent years, workers in the STEM field and enrollees in post-secondary STEM programs are disproportionately white, male, and middle-to-upper class (National Academies of Sciences, Engineering, and Medicine, 2019). Additionally, substantial scholarship has indicated that disproportionate representation in the sciences means disproportionate quantities of funds and research into issues that reflect a narrow group of interests, and even harmful and exclusive practices against women, disabled individuals, and black & indigenous people of color (BIPOC) (Green et al, 1997; Seto, 2001, Harding, 2015). As women, BIPOC, and disabled individuals continue to be on the receiving end of these systemic harms, it feeds a cyclical narrative of lack of *ability* to be successful in the STEM disciplines, when truly there is a pervasive lack of *opportunity* to access engaging and high-quality learning that begins as early as elementary schooling. Research indicates that particularly for low income and BIPOC students, K-12 schooling may not provide the learning opportunities needed for success beyond K-12 (Achieve, 2015; Barry & Danenberg, 2016; McFarland et al, 2018; TNTP, 2018). It could be argued that citizens can impact scientific work and research through means other than formal education or from within the STEM career pipeline, and while there is a historical and contemporary tradition of amateur or "citizen science", research indicates that this too is overwhelmingly white, male, and middle class, likely due to the time and expense needed to engage in science in one's free time (Strasser et al, 2019).

Research suggests that students from "non dominant" populations (Gutierrez, Morales & Martinez, 2009) are explicitly and implicitly discouraged from entering into the STEM fields and higher STEM education. Through their early and intermediate education, they come to feel that the sciences are not accepting of their individual and cultural knowledge (Brown, 2006; Regan & DeWitt, 2015; Calabrese Barton et al, 2013). Additional research attributes this to the often teacher-centered, fact driven, “conservative” instruction that has been common in science classrooms (Stroupe, 2014). The *Framework for K-12 Science Education,* a major theoretical document guiding US science education today, emphasizes a shift from fact-based, rote learning toward student centered, practice-based approaches (NRC, 2012), which many researchers have hailed as a positive shift toward science teaching and learning that is inclusive and responsive to marginalized students (Bang et al, 2017; Januszyk, Miller & Lee, 2016; Lee, Grapin & Haus, 2018). However, even in the wake of this guidance, research continues to document classroom instruction where content is pre-determined and investigations are not integrated coherently to support students’ interests (Cherbow, McKinley, McNeill & Lowenhaupt, 2019; Schwarz, Passmore & Reiser, 2017). Teachers who have been trained in and acclimated to traditional or “conservative” science education culture are likely to need significant support in shifting their instructional practices in order to better align with the goals of the 2012 *Framework*.

Preparing and supporting teachers in designing and delivering instruction that is all at once rigorous, meaningful, and culturally responsive is an important piece of addressing this disparity. Teachers are a critical component of student learning and the classroom experience - their beliefs about students and values related to teaching influence their teaching practices and therefore student outcomes (Haney, Lumpe, Czerniak & Egan, 2002). It is common for teachers of underserved populations to have even subconscious low expectations of students, informed by racist/classist ideologies that pervade the fabric of society (Timperley & Phillips, 2003). For example, Nasir and colleagues describe how common dominant “storylines” about students of color result in differential expectations and treatment (2012). In order for teachers to deliver high quality, culturally responsive instruction for all students, they first must truly value all of their students' voices and input and must believe that all students are capable of high-quality work. It would be beneficial to explore how a democratic science teaching framework, which centers student voice, authority, and critical literacy, informs the values, beliefs and ultimate practices that a teacher develops.

This case study focuses on the experience of one novice high school physics teacher, Jack, as he works to develop a classroom that is grounded in student voice, shared authority, and making science relevant to his predominantly BIPOC students. In a professional learning fellowship, he engaged with a Democratic Science Teaching (DST) framework (Basu & Calabrese Barton, 2010). With a fellow researcher, I visited Jack many times over the course of a year as he worked and reflected with other science teachers in the professional learning fellowship and attempted to implement "actions" aligned with the DST framework. Throughout the year, he grappled with ideas about what ideal science teaching *should* look like as prescribed by the DST framework, what he felt his instruction *actually* looked like, and the roles of himself and his students in constructing the culture of the classroom. In this work, I will explore how his entrenched and evolving beliefs about his students both influence and are influenced by his understanding of the DST framework. I will employ Hutner & Markman's operational definitions of activated beliefs as "mediating representations" between a teacher's goals and their contexts to guide my interpretation (2016). I will close with considerations for research and practice implications for the use of Democratic Science Teaching as a belief activator for teachers of marginalized students.

Theoretical Background: Democratic Science Teaching & Operationalizing Teacher Beliefs

Democratic Science Teaching (DST) was initially articulated by Basu & Calabrese Barton as a framework for science teaching that is "meaningful, authentic and just", with a particular focus on empowering marginalized students (2010). Having gone through additional iterations through work with teachers and students, the most current version of the framework is articulated in the text *Democratic Science Teaching* (Calabrese Barton, Basu, Tan & Johnson, 2011). The DST by design places high expectations on students and their abilities to select relevant and interesting content, contribute to the design of the class, and use science to effect change in their world. While the foundational research on the DST focused on identifying practices that already existed in classrooms, this work explores the possibility of using DST as a framework for teacher professional learning to influence teachers' beliefs and practices. Thus, the major theoretical considerations underpinning this study are the DST framework itself as well as understandings of teacher belief systems and their interactions with professional practice.

What is Democratic Science Teaching?

DST as articulated by Calabrese Barton, Basu, Tan & Johnson consists of three major principles: student voice, shared & transformational authority, and critical science literacy (2011). Student voice is grounded in the idea that students' ideas should be centered in the classroom, their discussion, ideas and work should be the focus. It is critical that the classroom offers "authentic opportunities to engage science in ways that validated [students'] voices and perspectives" (Basu & Calabrese Barton, 2010, p. 84). Shared & transformational authority embodies the idea that students can and should be able to make decisions about what they learn and how they demonstrate their learning, and that their knowledge is valuable in the classroom community. Students should feel "freedom" to make choices and have a sense that their voices are "honored" (Basu & Calabrese Barton, 2010, p.84). Finally, in a classroom that values critical science literacy, students develop strong content and practical understanding of science, are able to see how science connects to their world and understand how they can use it to answer questions and address issues that are meaningful to themselves and their communities. Furthermore, *critically* literate students come to understand that science is cultural, that those who do it are driven by values and motivations, and that it is often used to serve the interests of the powerful. A classroom that supports critical science literacy "challenges the socio-political context of how and why youth are taught to engage science in the current system" (Calabrese Barton, Basu, Tan & Johnson, 2011). In a democratic science classroom, students come to see science and science learning as something they and anyone can take ownership of, while recognizing the historical and contemporary power dynamics that exist to shape common cultural perceptions of science.

Teacher Beliefs and Practices

Writing in 2011, Lynn Bryan compiled a review of research on teacher beliefs, noting five key ideas:

> 1. teachers come into the classroom with a complex and interconnected "internal architecture" of beliefs
> 2. some of beliefs are more important than others
> 3. the more important or "central" beliefs are more resistant to change than others
> 4. because beliefs are so interconnected, changes in one belief can impact the entire system
> 5. finally, strongly held beliefs are more important than discrete "knowledge" in influencing an individual's behavior (p.478-479).

The practices of teachers are informed by the beliefs, principles, and values that are present in their culture. In other words, "we teach who we are" (Palmer, 1998, as cited in Howard, 2003). Teacher's beliefs will impact the kinds of activities that they will choose, the expectations that they will convey to the students, and the way they design their instruction (Pajares, 1992). This was exemplified in a large-scale 2020 study where researchers found that not only do many K-12 teachers in the US tend to have implicit anti-Black biases, but that those biases were directly correlated with lower student achievement outcomes and higher in-and out-of-school suspension rates (Chin, Quinn, Dhaliwal & Lovison, 2020). This provides evidence that teacher beliefs are relevant to students’ experiences in schools.

Yet even though beliefs and practices are closely intertwined, sometimes *stated* vision and beliefs don’t always mesh with practices. For example, Caleon, Tan & Cho (2018) explored the stated beliefs and observed practices of both new and veteran physics teachers. They categorized teachers' beliefs and practices as anywhere from “transmissionist" to “constructivist”. Their work identified four findings of interest to this study: first, that beginning physics teachers often held beliefs about teaching and learning that aligned with a “transmissionist” model - that students should receive information passively from the teacher, who should be the expert disseminating “ready-made” knowledge (p. 129). Second, those transmissionist beliefs and teaching practices were more common when teachers worked with students that they perceived as low-performing or low-ability. Third, more experienced teachers did tend to express more constructivist beliefs about teaching, often credited to professional learning experiences, even if their practice didn’t always match those espoused beliefs. Finally, even teachers who held constructivist beliefs about teaching would shift their practices if they felt concerned about their students’ readiness for the end-of-year high stakes examination. Jones & Leagon also explored this tension, identifying that while teachers may hold general beliefs about what is best practice for students, they may believe that a different approach is needed for “their" students (2014).

Hutner & Markman, drawing on ideas from Markman & Dietrich (2000) worked to explore the reasons why teacher practice did not always seem aligned to stated beliefs. They argue that “beliefs—including, but not limited to, beliefs about students, schools, science, and pedagogy—are a type of mediating representation” between an individual’s environment/context and their goals (2016, p. 678). A teacher’s beliefs mediate their experience of the environment, how they will perceive it to impact their goals, and will also mediate their goals in response to their perception of the environment. Hutner & Markman argue that this can happen both consciously and unconsciously, and that based on inputs from the environment, some beliefs can be "activated" more easily than others (p. 679).

Hutner & Markman's idea of "activation" provides to some clarity the seemingly contradictory findings by Caleon, Tan & Cho. Although veteran teachers adopted more "constructivist" views of teaching over time, believing that students overall learned *better* by constructing knowledge from experiences, initial low performance by students could activate other beliefs - for example, that some students lacked the *ability* to construct knowledge and required more teacher intervention and direct instruction in order to achieve learning outcomes. In the context of the US, this is exacerbated by the presence of high-stakes accountability, where teachers may feel pressure to "teach to the test" due to graduation requirements or possible repercussions against themselves or the school. Additionally, while race and class were not raised as contextual factors in Caleon, Tan & Cho's specific study, I posit that pervasive cultural narratives about ability based on race and class could certainly act as conscious or subconscious mediating representations in the US context. Deficit narratives about marginalized populations of students are pervasive in the culture of American schooling (Howard, 2003; Ladson-Billings, 1994). Additionally, Thomas Philip has written extensively about the varied ways in which STEM teachers, even teachers who profess a strong belief in social justice education, reproduce racist ideologies in their classroom & professional interactions (Philip, 2011; Philip, Olivares-Pasillas, & Rocha, 2016; Philip, Olivares-Pasillas, & Rocha, in press).

Professional Learning and Teacher Beliefs

Can professional learning grounded in Democratic Science pedagogy help to activate more asset-oriented beliefs about students? Can it contend with entrenched beliefs rooted in racist and classist ideology? There is research that suggests this is possible, at least under certain conditions. Generally speaking, effective teacher professional learning that results in change must allow opportunities for teachers to build content and pedagogical knowledge, and to explicitly reflect on that knowledge-building, and must model the practice changes that should be implemented (Loucks-Horsley et al, 2010). Perhaps most importantly, Loucks-Horsley and colleagues argued that STEM teachers must experience dissonance in professional learning - they must see evidence that their current teaching practice has room for improvement. This idea is echoed in other work specifically around anti-racist teacher education. Ohito argued that "embracing *discomfort* as pedagogy cultivated White preservice teachers' emotional openness to supporting each other in a learning community premised on political relationships as vessels for deepening critical consciousness about race, racism, and White supremacy" (2016, p. 459, emphasis added).

The last piece, and arguably most difficult to engineer, is that teachers must see their learning take shape successfully in the classroom (Jones & Leagon, 2014). This is an important implication for research, as it suggests that studies must follow not only what happens within the context of a professional learning institute or coaching session but must also explore how teachers put their learning into practice within their classrooms. Furthermore, some research suggests that teachers should have opportunities to further unpack their classroom experiences in additional professional learning time (Kazemi & Hubbard, 2008). Without positive feedback in the form of student engagement or academic achievement, and opportunities for teachers to make sense of their experiences in the classroom among a supportive group of learners, teachers will likely revert to familiar and more comfortable, traditional practices.

The Current Study

Informed by this work, this paper will explore a case teacher's experience over the course of a year as he engages with the Democratic Science Teaching framework in a professional learning session and in his classroom. Employing Hutner & Markman's idea of *belief activation* as a critical component in instructional choices, this study strives to address the following research questions:

1) What beliefs are activated over a year as a teacher engages with the Democratic Science Teaching framework?
2) How do those beliefs inform the teacher's instructional choices?

Study Design

This case study is embedded within a larger research study on a group of teachers involved in a year-long professional learning fellowship grounded in the DST framework. A case study was selected as a useful approach to "investigate a contemporary phenomenon in depth and within its real-world context" (Yin, 2018, p. 45). Understanding how the case teachers' beliefs were activated, and how they went on to inform his choices, is very much integrated with the specific context and time of his participation in the PD fellowship and concurrent implementation in his classroom. Although the case is primarily descriptive, some of the components of the case could be useful to inform other researchers or teacher educators working with new physics teachers. Throughout the year, two researchers including this study author attended the professional learning fellowship as participant-observers (Glesne, 2010), conducted classroom observations, and three rounds of semi-structured interviews with individual teachers. In this study year, fourteen teachers participated to varying degrees in the research. From those fourteen teachers, Jack was selected as an illustrative case of a novice physics teacher engaging with Democratic Science Teaching while he developed his foundational, practice-informed beliefs about his students and about science teaching. An illustrative case study can provide a "concrete example" of how an intervention functions in a real-world setting (Levy, 2008), while preserving the rich contextual factors at play throughout. This case of a new physics teacher interacting with the DST framework is not broadly generalizable but could help to identify further areas of research or possible supportive structures geared at new teacher belief development.

Focal Participant

Jack was selected as the focal participant for this case study as both a novice high school physics teacher and an exemplary participant in the professional learning fellowship (Yin, 2014). Jack is a White male teacher with a middle-class background, working with classrooms of predominantly Black, Latinx and low-income students. At the time of the study, he was in his late twenties. His mother had also been an educator and he expressed that talking with her about education, "sharing reactions to the latest Marshall Memo", and sharing ideas from his learning was an enjoyable activity for him. After completing an undergraduate degree in Biology, he spent some years working as a lab manager before returning to school to earn a master's degree in education. After completing the program, he worked for one year at a public high school in a major Northeastern US city, then moved to a public in-district charter school in the same city. This study took place in his first year at the charter school, and his second year of teaching overall. As the only physics teacher in his school, Jack was responsible for developing and implementing both the intro and AP physics courses. He had access to physics textbooks, although they pre-dated the most recent science standards. The school did not dictate or prescribe a specific curriculum, although Jack did consult the state science standards for the intro course and the AP standards for the physics course. In his interview for the fellowship as well as his first interview with the author, he expressed a deep awareness of his need to grow as a teacher, that his current teaching "does not match with [the ideal]."

As a new teacher, Jack provided an interesting case as he was at a state of his career where his instructional style, goals and beliefs about teaching were in a formative stage.

Researchers have identified a need for more studies to understand how new teachers in particular interact with professional development experiences (Davis, Petish & Smithey, 2006). Jack frequently positioned himself as a learner, as hoping for growth, and was open to influence from the DST framework and fellowship, as well as from other educators and leaders in his school context. This provided in Jack a useful case of a teacher who was actively shaping his identity as a teacher.

Jack sought out the DST professional learning fellowship because he was interested in receiving constructive criticism and reflecting with other educators around the practice of teaching. In his application to the fellowship he stated, "I love the idea of reflecting on my teaching and establishing a problem of practice." He also appreciated that the fellowship involved having the participants share out their strategies and learning at an end-of-year expo. More information about this expo and the details of the professional learning fellowship will be provided in the "Context" section.

Study Contexts

Two researchers followed Jack over the course of the school year in two major contexts - first, in the professional learning fellowship centered on the DST framework, where he was primarily participating as a learner. The second context was his own physics classroom at City Charter School[1], as he attempted to implement practices and strategies aligned with Democratic Science teaching. We felt that it was important to explore not only what Jack was learning in the official learning space of the fellowship, but also what he was learning as he implemented strategies in the classroom. Furthermore, his lived experiences as a classroom teacher created the context in which he understood and interpreted the content of their PD. Kazemi and Hubbard describe this as "coevolution of participation" (2008). The contexts of the school and the

[1] All names and places are pseudonyms.

professional learning fellowship cannot be treated as fully distinct from one another, and key understanding of how and why Jack's beliefs are activated in certain ways, or actions that he chooses as a teacher, may only be well understood if these multiple contexts are examined.

During the study year, Jack was in his first year of teaching at City Charter school, and his second year of teaching overall. Jack taught both introductory 11th grade and AP physics courses. The student population at City Charter was over 95% Black and Hispanic/Latinx, over 70% low income, and over 80% students designated as "high needs" by the state. In his pre-interview, Jack described the school as "a college-bound school", "a positive and academic culture", and having "a reputation for very high academic standards." This was in contrast, he said, to his previous school, Turnaround High, where he described a culture of lower expectations for students. As stated previously, Jack was the sole physics teacher on staff at the school, and while he was expected to align his teaching with the state and AP physics standards, there was otherwise little guidance on the content of his teaching. As his college major had been in life sciences, he felt that he had a general grasp of the content, but did express that particularly with the AP coursework, he felt a need to "catch up" periodically to feel really prepared to teach.

He had heard about the Empowered STEM Teachers (EST) fellowship from a colleague at Turnaround High and found the opportunity to connect with other science teachers appealing. He stated, "I have so much room for growth and so I'm constantly looking for ways to develop as a teacher" (Application interview, November interview). He hoped to build connections with other science teachers who could help him improve his practice. The Empowered STEM Teachers fellowship was a series of facilitated workshops built around Democratic Science Teaching as its foundation. Throughout the year, teachers would learn about the DST, then use it as a guiding framework to collect data from their classrooms, identify "problems of practice", generate solutions, and collect data again to determine the effectiveness of those solutions.

Finally, they would present their learning as a narrative project called a "window into the classroom" or WIC. This iterative design process was built around the "Beehive model" of professional learning shown in Figure 1 (Innovations for Learning, 2012). Intended to invoke the idea of "the power of collective activity", the Beehive model lays out a process in which teachers work together and apply a design process framework to identifying and addressing classroom problems of practice. Relevant to this study, the model emphasizes the importance of engaging directly with students as partners in identifying problems and brainstorming possible solutions.

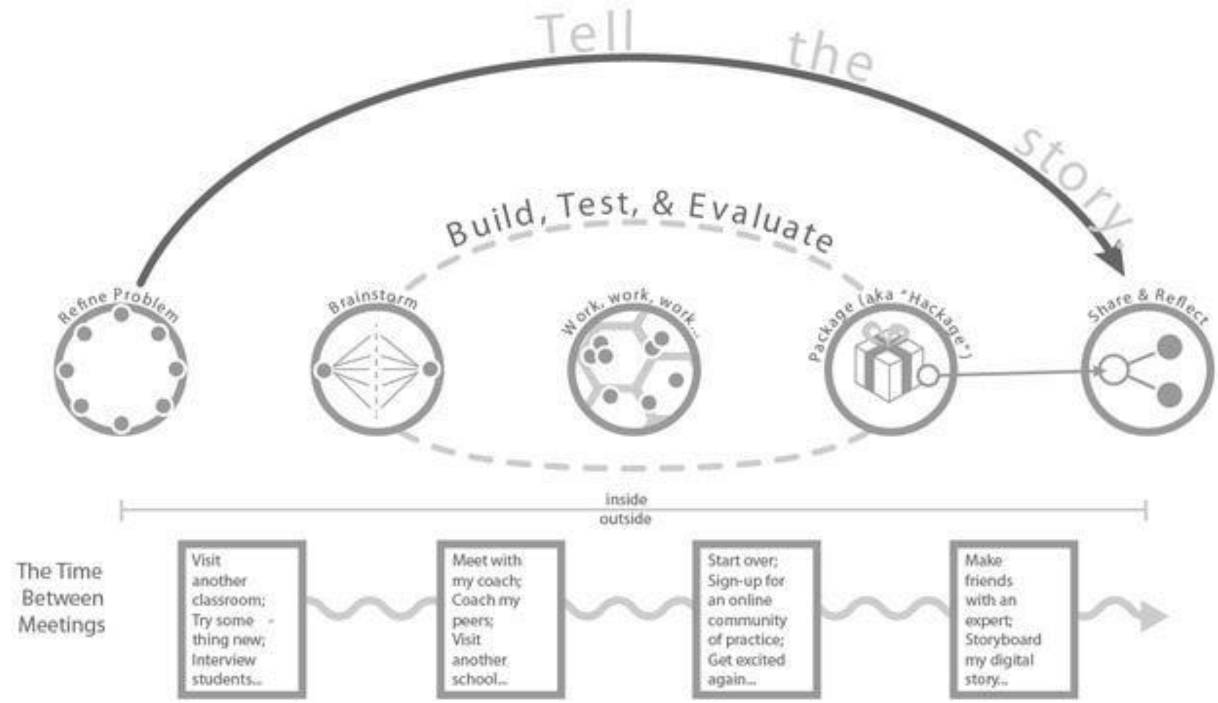

Figure 1. Learning Cycle Model: "Beehive" professional development (Innovations for Learning, 2012).

During the school year, they completed two cycles of this process, with WIC presentations occurring in January and June. The workshops served as places to connect and brainstorm with other fellows who served as "critical friends" - providing encouragement but also critical feedback in order to push each other's thinking. A more detailed overview of each workshop is shown in table 1. There are purposeful parallels to the Beehive model as each workshop session lines up with the steps in the process, including identifying problems of practice, brainstorming solutions, and reflecting on implementation. One area of intentional difference is that the introductory sessions ground the work in the Democratic Science Teaching framework, as well as supporting teachers in finding parallels between the framework and the science and engineering practices. This is intended to ensure that teachers use the framework as a guiding lens for them as they identify problems, collect data, and develop actions.

Table 1. Workshop Activities and Assignments by Month

Month	Workshop Activities	Homework Assignment
August	2 Day Kick-off workshop, getting to know you activities	Take video of "typical" instruction in the classroom
September	Deep dive into Student Voice principle, overview empathy interview protocol	Conduct empathy interview with at least 1 student
October	Deep dive into Shared Authority principle, discuss empathy interview results	Pilot techniques to increase shared authority, find readings that relate to CSL
November	Deep dive into CSL principle, discussion of attempts at shared authority	Develop and administer surveys to students that gauge level of CSL in the class
December	Overview of how to develop Windows into the Classroom narratives (WICs) for January showcase, work time	Develop WICs for January Showcase
January	No workshop, January public showcase	
February	Debrief January showcase, deep dive into "design thinking" framework for DST action plan	Conduct interviews and observations of students to identify Problem of Practice

March	Use observation and interview data to develop a Problem of Practice (PoP) area of focus and possible action plan	Implement and collect data on Action Plan
April	Draft WIC for spring semester PoP/Action plan cycle	Continue to implement Action Plan and collect data, develop WIC
May	Coached WIC work time	Complete Action Plan and WIC
June	No workshop, June public showcase/expo	

Data Generation

The data for this study include video, audio recordings, interview transcripts, observation forms and artifacts from Jack's participation in the fellowship. Chronologically speaking, the "first" piece of data was Jack's application video, which he submitted during the summer preceding the fellowship, and the notes from his interview, which were taken by one of the EST fellowship facilitators. During the school year he participated in three rounds of semi-structured interviews that lasted approximately 40 minutes each in early November, late January, and late May. These interviews were conducted by me and an additional researcher, and they all took place at Jack's school shortly after school. Although more frequent formal interviews would have been beneficial, this schedule reflected the capacities of the research team and of the teacher, given that a number of teachers were being interviewed in the context of the larger research project. We transcribed the interviews for review.

In addition to the interviews, we conducted ten classroom observations over the course of the year. We alternated visits so that each researcher conducted 5 visits. Before each observation, we asked Jack to let us know via email if there was an area of the DST that he was purposefully trying to implement and offered to provide our observations and questions afterward. Due to student privacy concerns, we were unable to take audio or video, but rather used an observation form to document what we noticed (see Appendix).

In each of the 10 workshops, we took field notes and audio. We took audio specifically from small-group conversations that Jack was involved in, with consent from the other members of the group, and we took field notes during the whole-group conversations and a total of 10 small-group conversations. When we attended workshop sessions, we utilized a participant observer model for researchers (Glesne, 2010). Both researchers were former middle school science teachers, and we could draw on our own learning and experiences as educators in our participation. We participated in whole group activities, sharing experiences from our own teaching, and providing feedback when it was solicited. We transcribed the audio recordings taken from the small group conversations.

Finally, we collected artifacts in the form of brainstorming documents that were generated during the workshop, co-planning documents, and Jack's own documents that he used to develop his problem of practice, solution, and WIC. These documents were shared Google doc files that contained the "homework" from each session. Jack would add entries and the EST facilitators would populate with comments and feedback after each workshop. We also had access to Jack's mid- and end-of-year WIC presentation videos, as all participants in the fellowship recorded their WIC presentations to populate a video library for future cohorts to access. These sources are summarized for reference in Table 2.

Table 2
Data Sources

Format	Description	Generated	Quantity
Video			
	Application video	Summer 2018	1

	Classroom video clip	September 2018	1
	WIC Screencasts	January & June 2019	2
Audio			
	Semi-structured interviews	November 2018, January and May 2019	3
	Workshop small group recordings	Throughout the school year	10
Field notes			
	Classroom observations	Throughout the school year	10
	Workshop observations	Throughout the school year	8
Archival			
	Jack's ongoing planning document with coach comments	Throughout the school year	1
	Collaborative planning posters and documents from workshop	Throughout the school year	8

Data Analysis

Analysis took place in multiple stages. In the first stage, I organized and read through the data chronologically, from Jack's application materials through his final WIC presentation and narrative, in order to gain a "holistic view" of Jack's thinking over the year (Braaten & Sheth, 2017). At this point in analysis, I did not have a precise research question but wanted to get a sense of Jack's experience engaging with DST as a relatively new physics teacher. In this read through, it was clear that Jack was working through many of the typical challenges of being a relatively new teacher - developing a classroom management style, staying on top of planning, refreshing his content knowledge at times - and was using the DST to conceptualize an ideal classroom to work toward. He frequently discussed the apparent gap between his vision and beliefs of “ideal” science teaching and his actual, day-to-day practices. This read-through motivated the final articulation of the research question, as well as the focus of this analysis on the interplay between teacher beliefs and actions, and the role that the DST was playing in the activation of key beliefs.

The second stage of analysis involved a round of “values coding” (Saldana, 2021, p. 167). In order to address the research question and examine beliefs and values that were being activated in instructional choices, I chose to attend specifically to the beliefs that were being raised throughout the interviews, observations, planning materials, small group conversations, and narratives. I also paid particular attention to areas where beliefs were linked explicitly to an action, however, there were also instances where an action appeared to have an underlying belief of value. Table 3 shows different examples of this – in one instance, the teacher explicitly stated that his classroom actions were connected to a specific belief. In another example, he describes an action that he took, and later in the analysis process, I identified likely underlying beliefs based on other statements made by the teacher. In this stage of analysis, I tried to tag any belief, value or attitude that was expressed, even if it was not at that time explicitly or implicitly linked to an action. I generated memos throughout this stage as I began to notice initial patterns across the data.

Table 3: Examples of Quotes and Related Codes

Example 1: Belief and explicit linked action	
Quote	Code
I have so much room for growth And so, I'm constantly looking for ways to develop as a teacher and so looking for any opportunity to talk with other science teachers about how to be a better science teacher	Belief: room for personal growth Linked Action: seeking ways to develop. Linked Action: looking to talk with other science teachers

Example 2: Action with underlying linked belief	
Quote	Code
I have trained my [intro physics] students to be very dependent on me and [me] telling them exactly what they need to do and what the right answer is.	Action: consistent teacher-directed instruction Underlying linked belief: *these* [intro physics] students will not learn physics without explicit direction from the teacher

In the final stage of analysis, I looked for patterns of beliefs and actions across the corpus of data. Employing my research question, I sought to find out what beliefs were activated over time as Jack engaged with the DST and how those beliefs were or were not translated into classroom actions. This analysis resulted in four overall themes that will be explored in detail in the findings section:

1. Engaging with the DST framework activated teacher beliefs that are aligned with student-centered classroom experiences.
2. Engaging with the DST framework informed Jack's actions to facilitate voice, ownership, and relevance for students.
3. Pressures from the school culture around specific learning outcomes informed Jack's belief that the teacher, ultimately, drives student learning experiences, and led him to act in more teacher-centered ways.
4. Workshop structures, when present, supported beliefs and actions aligned with the DST – though additional structures could have been helpful.

Findings

Engaging with the DST framework over the course of the year kept Jack's classroom vision - one where students are actively engaged in asking questions, conducting investigations, and developing their own ideas about findings based on data - activated as a goal, even if he felt that his cultivation of such a classroom fell short. Pressures from within the school environment and overarching ideas about what students "should" learn activated a conflicting belief that the students needed more teacher direction, making it difficult for Jack to authentically integrate shared authority in this classroom. Finally, the professional learning fellowship provided some structures to support Jack in making strides toward his vision - a student driven classroom where students constructed their own knowledge - but the support was perhaps not intensive or responsive enough to counteract the pressure to address the "correct" content in a limited timeframe. Ultimately, he attempted to resolve these conflicting beliefs by incorporating phenomena-driven curriculum units into his classroom as his final "WIC" project. Next, I will describe the four themes that emerged from this analysis. In particular, I will demonstrate how the DST framework, and the contexts of the professional learning fellowship and school culture all played a part in informing Jack's beliefs and actions in the classroom.

Engaging with the Democratic Science Teaching Framework activated beliefs aligned with student-centered classrooms,

Engaging with the Democratic Science Teaching framework supported Jack in holding up student voice, shared authority, and critical literacy as an ideal or goal, and had a clear influence on his vision for science instruction. In a November interview, he explains his ideal classroom as one where students drive their learning: "I'm putting my students in situations where they're doing science or they're asking interesting questions and collecting the data to answer those questions and using the skills - to take that data and come away with a bigger conclusion about some scientific principle." In January, he again described his ideal as "I want them to be doing things, observing things, coming to conclusions about, noticing patterns and what they're observing and then coming to bigger physics concepts because of that. And then more generally learning how to think critically and not just following steps." In May, he returned to a similar idea:

> students [get] this impression that science is this big amount of facts and you just need to memorize them to understand how the world works…I think a much more valuable thing to take away from a science class is the idea of how to think scientifically. And if we want to answer a question, how can we take the tools that we have and design an experiment to learn about something.

Here he critiques a common idea about science as a body of facts to absorb and places a value on students' ability to make sense and determine an appropriate process to investigate, all actions aligned with critical science literacy. Throughout the year, he lifted up this vision for an ideal classroom, where students think scientifically and are empowered to come to their own conclusions.

Engaging with the DST Framework informed Jack's actions to facilitate voice, ownership, and relevance for students.

Regarding the second research question, how his beliefs translated into classroom practice, Jack identified a few specific actions aligned with the Democratic Science Teaching framework. Throughout the year, he engaged his students in activities where their work was shared with the class and discussed with the group. In one protocol that he used consistently throughout the year, he selected samples of student responses and showed them to the class using a document camera. The students then discussed the response and indicated agreement or disagreement with the work and were able to ask the author questions about their process. For example, in a November classroom observation, he began the lesson by sharing a student's response to a homework assignment on balanced and unbalanced forces – with the student's permission. The students were asked to evaluate the student's explanation of the forces present in a diagram, and to justify their own comments with evidence. This functioned as a quick activator for students, a way to practice peer evaluation, and aligned with both student voice and shared authority in that student work was centered and the students were positioned as the knowledgeable experts in the classroom.

In another protocol, he had students group graph data from their investigations on a whiteboard. He then called a "board meeting" where students found "similarities and differences in the data and [came] to a conclusion…to a consensus". For instance, in one February lesson, students spent most of the class period exploring circuits and were asked to come up with a rule – "when x conditions are met, the light bulb lights up". Students drew diagrams of the circuits that worked and shared them at the board meeting, where they identified common components of their diagrams. In this way, students were again positioned as the knowledgeable experts in the classroom, as they were tasked with identifying the conditions that would light up the bulb.

Finally, at the end of the school year when he decided on using phenomena-driven units as his DST-informed "action" to try out, he leaned heavily on the idea of critical science literacy as the driving rationale for his choice. He explained that he surveyed his students and when he asked if they could see real-world connections between the physics content and the "real world", about 70% of the class generally agreed, but only about 50% of the class could give a specific example. He stated, "I want them to feel that everything they're learning directly applies to something in the world." So, his decision to begin incorporating real-world anchoring phenomena to launch his units was grounded in his belief that it would support students' critical science literacy. In the final unit of the year, he allowed students to choose a thermal-energy related phenomenon to explore, such as an ice cube melting in a hand or a hairdryer causing water to evaporate from hair. The students drew initial models of what they thought was occurring. Then the class went through a series of investigations and readings about thermal energy transfer and refined their models. In this way, students applied their learning directly to real world contexts.

Pressures from the school culture around specific learning outcomes informed Jack's belief that the teacher, ultimately, "drives" the learning experiences

Despite making progress towards a classroom aligned with Democratic Science Teaching, other pressures within the school occasionally steered Jack in a different direction. At the beginning of the year, Jack's ideal vision was one where his students would lead the process from question development to drawing conclusions. By the end of the year, his stated ideal was more grounded in students being able to determine the steps to take in order to figure out a question or phenomenon *posed by the teacher*. This shift seems to be the result of other pressures, namely his perceptions around the content that students need to know and the skills that students need to have by the end of the year in order for them to succeed on standardized tests and in higher education. He stated in May, "Because we have a finite amount of time, you're going to prioritize labs and things that quickly get to the content that they need to learn and don't quote 'waste as much time'." In this he seemed to recognize that spending time on more inquiry aligned work was not actually a waste of time, but still the belief was activated that he must address the content in a timely way.

Other staff at the school also provided feedback that, arguably, pushed Jack in a more teacher-centered direction. In January, Jack described a new goal that arose as a result of his work with a literacy coach at the school:

> One goal that I have in the last half of the year, [is to] get my students to be better at reading about science. Yeah, so improve their science reading, literacy, and that's related to their success in science courses and in college. And that also is related to my feeling

> that students are more in a teacher-centered classroom nowadays… it's been feeling a lot like the Mister [last name] show in class recently.

Although he framed this as a skill that would make the students more independent learners in the long run, he recognized that he was the one setting the purpose and the agenda for the readings.

He spoke more about the pressure to teach specific content in his last interview of the year, saying “Our education system in general [prioritizes] students like learning *things* and meeting specific standards. And so, we're prioritizing these discrete content standards, and teachers are pushed to teach these students a lot of *things*.” This belief that students needed to be introduced to specific skills and content within a limited amount of time presented a barrier to Jack truly sharing authority with students. In January of the school year, he spoke about student discussion in his class:

> I find myself doing turn-and-talks and share-outs much less frequently because they don't produce the conversations that I want them to produce. They're a lot of side conversations or I get a lot of ‘I don't know’. Then I wind up fading away from student voice and being like ‘Okay well here's the answer.’ And I know that that's not the right teacher move to do, and then I get mad at myself because I haven't made [my classroom] the environment where doing the right teacher move is the more productive, fruitful thing to do.

Throughout the year, Jack made similar remarks about feeling unable to see his goals through because he felt an urgency to get students “on task” or producing “high quality” work. The pressure to get students to a specific academic outcome within a limited timeframe was constantly in direct tension with a desire to allow students to select and make sense of topics that were meaningful to them.

Workshop structures supported beliefs and actions aligned with the DST

The workshop facilitators directed the teachers to survey and interview their students throughout the year, and these activities were intended as scaffolds to support teachers in soliciting student voice. Reflecting on an interview with one of his students held during October of the school year, Jack wrote, "A big takeaway from the interviews was a renewed awareness of the multidimensional young people our students are…By thinking about our students as equally stressed out people with many things going on in their lives I know I have been approaching the small interactions I am having with students with a renewed sense of patience, caring, and empathy." Both of the students that Jack interviewed were Black male students who he had described as sometimes "disengaged" in class. The interviews seemed to be a promising way to allow more empathy and understanding into his relationship with them.

Additionally, the data from a survey taken in the second half of the school year - in which many students stated that they could see how physics connected to the "real world", but few could give an example - led Jack to decide to integrate real-world, anchoring phenomena into his physics units. In the last quarter of the school year, Jack articulated a goal that every science unit would be launched using an "anchoring phenomenon", a structure that he was introduced to by a colleague in the fellowship. In the way that Jack used it, students would select from a few choices of related phenomena at the beginning of a unit - such as an ice cube melting on a dish or a sunny room warming up as the launch for a unit on heat. Then over the course of lessons, readings, and investigations, they would develop increasingly complex models of the phenomenon that they selected and share their final models with other students in the class. In this way, the structures of the professional learning workshop activated beliefs and resulted in actions toward a more responsive classroom. Students had a choice in a phenomenon to model, had voice and some components of shared authority in that they presented their learning to one another, and each unit was now directly linked to a real-world experience for students, addressing components of critical science literacy.

Discussion and conclusion

The objective of this research was primarily to identify the beliefs that were activated over a year for a case teacher as he engaged with a Democratic Science Teaching framework. Overall, although there were external and internal pressures for Jack to revert to models of teacher control, the ideas from the DST framework itself and the structures and assignments from the professional learning workshop kept the vision of a student-centered classroom activated as a goal. As a result of these ongoing, often contradictory forces influencing Jack's ideas, he took several actions throughout the year towards soliciting more student voice and trying to support students' understanding of real-world connections to the science content that they were learning, but struggled to share authority with students in terms of supporting them in making decisions about what and how to learn.

These contradictory forces seem to represent conflicting accountability paradigms for in-service teachers. Cochran-Smith and colleagues described the mainstream or "dominant" paradigm as a system of accountability defined by an emphasis on individual success, external accountability systems that mandate standardization, and the need to prepare students for the workforce (2018, p. 190). By working in public schooling, Jack is held to the standard of the dominant accountability paradigm, which emphasizes science as a body of information that students must be able to know and perform in order to achieve success. This leaves little time or room for sharing authority with students and to some extent critical science literacy, as students' diverse values and interests are not considered as important foundations for learning as externally imposed standards. It is likely that the internal concerns that Jack expressed throughout his year in the fellowship also represent the ways that the dominant accountability paradigm influenced his own schooling and teacher education, and therefore activated beliefs that troubled his confidence in his abilities to facilitate a student-centered classroom. In a similar vein, Allen and Penuel identified the “multiple and sometimes competing messages from PD leaders, building administration, students, as well as their prior teaching experiences and…education degree programs” as a major source for uncertainty and ambiguity that could create struggles for teachers in trying to design learning experiences for students (2015). Drawing from their work, it’s possible that the professional learning program could have been improved by providing more space for teachers to wrestle directly with these tensions and conflicting demands, and to support one another in developing a coherent understanding of what was being asked of them on all sides.

With all of this said, the pervasiveness of the dominant accountability paradigm makes it all the more meaningful that despite it, Jack maintained the goal of a classroom where students posed personally meaningful problems, generated their own procedures to address them, and were able to interpret and draw conclusions from the data. Participation in the fellowship provided permission, space and some guidelines for how to enact these beliefs. In the Empowered Science Teachers fellowship program, the teachers were held accountable to a different standard, one more aligned with a democratic accountability paradigm. In this paradigm, “the goal is preparing teachers who create democratic learning environments that enhance students’ academic, social, and emotional learning and also prepare them to participate constructively in a complex, diverse, and divided democratic society” (Cochran-Smith et al, 2018, p. 195). Teachers operating in this paradigm would value diverse ways of thinking and representing ideas and would be encouraged to do so within their school systems. By valuing students’ individual voices in the classroom, working to empathize with students and create science experiences that were meaningful, and by allowing students choices in the phenomena that they investigated and later on explained, Jack sought to meet the criteria put forth by the EST fellowship and the DST framework. Still, particularly for new teachers, future iterations of the program could support teachers by providing more explicit guidance and support, or even a supportive conversation space, around the challenges of navigating and implementing the DST framework in the context of meeting state standards and navigating the political culture of school environments. For example, although time was spent at the beginning of the fellowship to identify ways that the DST could align with the science and engineering practices, revisiting these ideas throughout the program could be beneficial.

The findings of this work contribute evidence of democratic accountability in action, albeit in a small and contained way and not in the transformative way that a true paradigm shift would. The EST fellowship provided a framework for Democratic science teaching as well as structures such as student surveys, interviews, and talk protocols that a teacher could use to foster DST in their classroom. Despite institutional pressures to do otherwise, Jack valued and put efforts toward developing a more democratic classroom. K-12 educators, teacher educators, and other stakeholders who are interested in expanding student participation in science might look to build their programming around a Democratic Science Teaching, with program supports and outcome expectations aligned with strong equity and strong diversity.

Limitations and suggestions for further research

As an individual case study bounded by one year, this research is limited, and the findings would be difficult to generalize to a broad population of teachers. Still, the themes of Jack's struggle to navigate the conflicting demands of the traditional accountability system of the school with the democratic vision of accountability articulated by the program are not unique and present an additional viewpoint in the overall discourse of the many contexts that influence and complicate the work of teaching. Jack's eventual solution of integrating standards-driven, real-world phenomena with student choice could be one example of a useful strategy for teachers who feel similar pressures to both teach required, but to make it meaningful and provide choice to students. More and larger scale research on the impact of professional learning grounded in democratic science teaching is needed to make a strong case that such fellowships could provide democratic accountability for teachers that is strong enough to counter, even in small ways, the dominant accountability paradigm. Additionally, while Jack made strides in his classroom to foster more student voice and critical science literacy, in many ways due to the supports and suggestions he received in the program, he struggled with sharing authority with students. Future studies aligned with democratic science teaching could be done to identify useful strategies and internal program structures to support shared authority. Finally, longitudinal research would be useful to determine the long-term impact of democratic science teaching programming on educators beyond the program year.

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Paper 2 Appendix A: Teacher Interview Protocols

Pre-Interview:

Before the interview starts: I'm interested in learning more about you and your classroom, and your experience in the workshop and with the DST framework.

Before we get started, could you state your first and last name and school?
And is it okay for me to record this interview?
I'm going to turn on the recorder and ask you to say those things again, and get your permission again on tape, then we'll get started.

A. The first few questions are meant to get some background about you, your students, your goals, and your classroom.

- What drew you to this fellowship?
- Can you tell me about your classroom culture?
- Can you tell me about the students you teach (demographics, characteristics)?
- Can you describe the overall culture of the school you work in?
- What are your goals for your classroom?
- What would ideal science teaching look like to you?
- How do you think your current teaching matches up with that vision, and why?

B. These next questions are meant to help me understand how you are thinking about Democratic Science Teaching after having had a bit of exposure to it in the first few weeks. I am not trying to "test" you, I just want to see how you're interpreting the DST in your own context.

- How would you describe Democratic Science Teaching to a colleague? (If you feel like you're unsure about any part of it, that is just fine and please just let me know - I want to get a sense of what's coming through well in the workshops and what's not.)
  - If they don't address the principles, prompt: What does each one mean?
  - Student voice. Is it present in your classroom? (Don't worry if it hasn't but if it has, how so?) - existing example in your classroom - how do you think it may play out in your classroom
  - Shared authority. Is it present in your classroom? If so, in what ways?
  - Critical STEM literacy/agency. Is it present in your classroom? If so, in what ways?
- Is there anything you do in your classroom that doesn't fall under the DST framework, but still could be called "democratic"?

C. In the last set of questions, I'm interested in getting at how you think the DST relates to your students in particular.

- What opportunities do you think DST presents for your students in general/students in your classroom?
    - follow up: how about your (non-dominant groups mentioned in question 1) students?
- What challenges do you think DST presents for your students in general/students in your classroom?
    - follow up: how about your (non-dominant groups mentioned in question 1) students?
- In the past weeks you have been interviewing students about their experiences.
    - What have they been saying? Anything surprising?
    - Has it been helpful for you as a teacher? In what way/why not?
- How do you expect your students will respond to your implementation of the DST framework in the second half of the year?
    - Why do you think that?
- Do you have any last thoughts or ideas about the DST, the fellowship, science teaching, etc. that you feel like you haven't had a chance to say?

Mid-Interview:

In our last interview, I asked you generally about your classroom and school culture.

- What would you say has stayed the same since the beginning of the year? What has changed?

These are the goals you described for your teaching this year (allow teacher to read responses)

- Would you say those have stayed the same or changed at all?

- How about your ideal vision? This is what you mentioned at the pre interview, how has it changed, and how have things played out so far this year?

How has participating in the DST workshops affected either (have a printout listing the DST principles handy so that they can refer back to them):

- Your goals for your teaching practice?
- Your actual teaching practices?

Over the past few months, you've been asked to brainstorm and implement a few actions to bring the DST into your classroom, and to get student feedback through interviews and surveys.

- How do you think this has benefitted your students?
- Is there a student in particular who you feel is benefitting from DST?
- Has this presented any challenges for your students?
- Is there a student in particular who you feel is finding this challenging?

During the second half of the school year, you'll be designing and trying out a bigger "action plan" to bring the DST into your classroom.

- Can you tell me about what you're planning?
- How do you expect your students to respond to this?
- Can you think of an example of a student in particular who may/is benefitting from it?
- Why do you think that?

Do you have any last thoughts or ideas about the DST, the fellowship, science teaching, etc. that you feel like you haven't had a chance to say?

Post-Interview:

In our last interview, I asked you generally about your classroom and school culture.

- What would you say has stayed the same since the beginning of the year?
- What has changed?

- These are the goals you described for your teaching this year (allow teacher to read response) Would you say those have stayed the same or changed at all?
- How about your ideal vision? This is what you mentioned at the pre interview, and mid-interview, how has it changed, and how have things played out so far this year?

How has participating in the DST workshops affected either (have a printout listing the DST principles handy so that they can refer back to them):

- Your goals for your teaching practice?
- Your actual teaching practices?

Can you summarize the final DST problem and solution that you came up with that will be in your WIC?
(Possible probes/clarifies here: How and why you chose it? What data was useful? Tell the story of your journey from workshop 1 to your final WIC.)

- How did your students respond to it?
- What was successful, and what was challenging about that?
- Can you think of a student in particular who really thrived when you took up that solution? How?
- Can you think of a student in particular who really did not seem to like it or do well with it? Can you describe why?
- What is/are the most important things you feel you've learned from the workshops or in your overall experience with the DST this year?

How, if at all, do you think the DST practices could be beneficial for students who have been historically marginalized in STEM, such as students of color, bilingual students, and students in poverty/low SES students, students with learning disabilities?

- DO you think these practices are in any way not helpful for those students?

Do you have any last thoughts or ideas about the DST, the fellowship, science teaching, etc. that you feel like you haven’t had a chance to say?

Paper 2 Appendix B: Classroom Observation template

Date: ______________ Observation Time: ____________________Classroom: _________________ Teacher: ________________

Democratic Pedagogy 2018-2019

Components of Democratic Pedagogy	**Student Voice**	**Shared & Transformational Authority**	**Critical Content Literacy**
Description & Guiding Questions	The idea that students' ideas and opinions are an integral part of growth and knowledge acquisition within a classroom.	The idea that student investment and achievement increase as their involvement in how they learn and apply their knowledge increases.	The idea that students are empowered to take action after learning about and reflecting upon contemporary issues that affect their lives.
Teacher's DST Goals & Areas of Focus	This will be provided before the observation via email **or** in person (teacher's preference). *Time: 2-5 min* 1. What are your DST goals for this lesson? 2. Keeping your DST goals in mind, what do you want me to look for in this lesson?		
Guiding Questions	**Guiding Qs:** 1. How, when, and why do students **express voice**? 2. How and when do **teachers cultivate and leverage** students' ideas and opinions?	**Guiding Qs:** 1. What **choices** are available to students? How often do they get to make choices? 2. How is the **curriculum situated around students** (situated in Ss' life experiences, home lives, backgrounds, and cultural and social identities)? 3. When, why and how often do Ss **leverage their knowledge and experience**?	**Guiding Qs:** When why and how often do students…. A.) **Investigate science and science education** from a **critical lens**? (Documenting issues of power and injustice) B.) Demonstrate **subject-matter expertise**? (Rigorous knowledge of content and NOS issues) C.) Leverage **subject matter expertise to reflect and act on relevant and personally meaningful issues** (e.g., injustices in their lives)?
Evidence	I will take notes here during the classroom observation (looking for		

	evidence of DST principles related to teacher's DST Goals		
Reflection	I will include reflection questions here (with the goal of pushing teacher's thinking around DST) and provide positive feedback		

Notes

Time	Description	Notes

Paper 3: Practitioner Piece - Using Student Surveys, Interviews, and Photo-journals to Build Connections Between Content and Context

Introduction

Have students ever asked you a version of “how am I going to use what I’m learning in this class?” In Jacki’s Biology classroom, students could often be seen engaging with hands-on labs and activities to explore concepts such as DNA structure, the cell cycle, and human body systems – all topics with connections to personal lives that, at least to an educator, seem clear. A science teacher with a strong grasp of the material can usually point to multiple applications for any given concept, but this results in students’ skepticism and glazed eyes as much as genuine conviction. Despite these efforts, students often perceive their lived experiences as divorced from the lesson and the work they are doing in class. Students need to be guided and empowered to see for themselves how what they are learning in class matters in “the real world”.

Democratic Science Teaching

The Democratic Science Teaching (DST) framework can be one approach for teachers to support students in making those meaningful connections (Calabrese Barton, Basu, Johnson & Tan, 2011). Practically speaking, Democratic Science Teaching (sometimes called Democratic STEM Teaching or DST) is an organizing framework that educators can use to guide classroom management, curricular choices, and instructional moves. The framework is composed of three primary principles: Student Voice, Shared and Transformational Authority, and Critical Science Literacy.

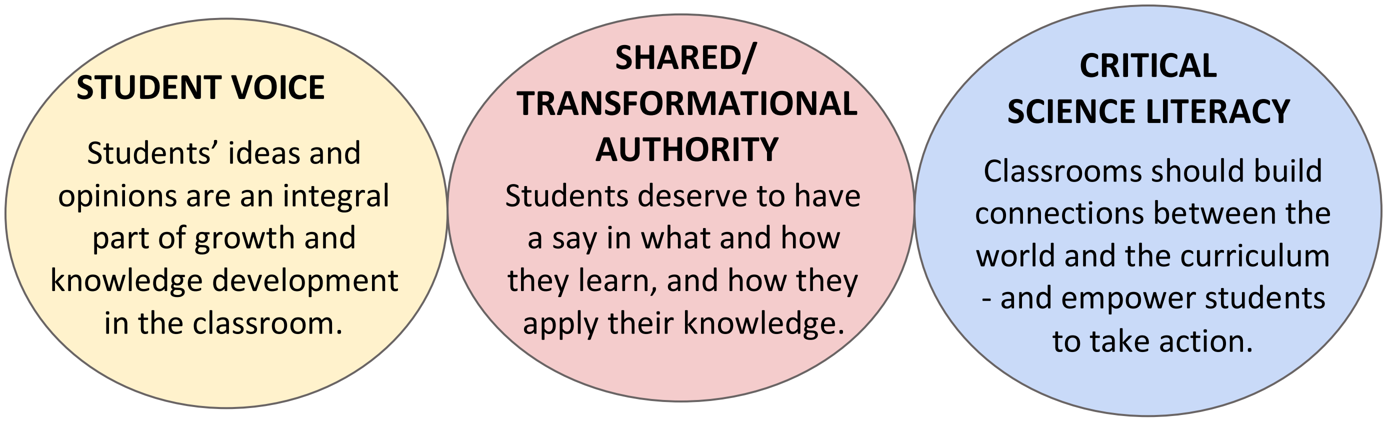

Figure 1: Democratic Science Teaching

Student voice references the idea that classrooms should be spaces where students' ideas are shared. Through discussion, debate, and written work, it is their questions and ideas that should be centered. Shared and transformational authority proposes that students should have choices about what they learn and how they demonstrate their learning, and that this sharing of power is transformational for students' learning. Finally, students should develop critical science literacy by engaging not just in passive consumption of science facts, but by interrogating who does science and how, and gaining enough competence in science as a practice that they can use it to affect meaningful change in their own lives and communities.

In this article, I will first take a deep dive into the principle of student voice and explore how a high school biology teacher used feedback from students to make changes to her classroom. I will describe how she took the feedback to develop a photo journal project that supported her students in understanding how their learning in the science classroom. Then, I will provide an overview of other tools that teachers have used in order to make their science classrooms more democratic spaces for students.

Use Student Voice to Find Root Causes of Disengagement

One clear dimension of student voice is the idea of *students talking to one another* productively, through discussion and debate with one another in the classroom. There are several excellent resources available to support "student talk," such as structured routines to support talk for different purposes (Wingert & Reinhart, 2016). But another dimension of student voice is the idea of *student communication with the teacher*. It is common in classrooms for teachers to pose questions to be answered by students. But in the interest of expanding the ways that students talk to teachers, two tools that can be useful are surveys and empathy interviews. Classroom surveys are useful for getting broad data about the class. In the context of the DST, teachers may choose ask questions to better understand students' preferences around learning activities, to identify areas where students are satisfied or dissatisfied with the class, and to explore whether and how students saw connections or relevance to their lives in the classroom content. In contrast, empathy interviews, taken from design research, can help teachers get a deeper understanding of specific students' experiences inside and outside of the classroom. Learning Accelerator provides an empathy protocol for educators and school leaders to learn from the students and families that they serve. Figure 2 shows an overview of the themes that should be addressed during the empathy interview process. Notably, empathy interviews as conducted by teachers should not focus solely on the student's classroom experience but should allow for the student to provide context about their lives and interests including and beyond school. Table 1 provides some examples of questions that teachers used on class-wide surveys as well as empathy interviews.

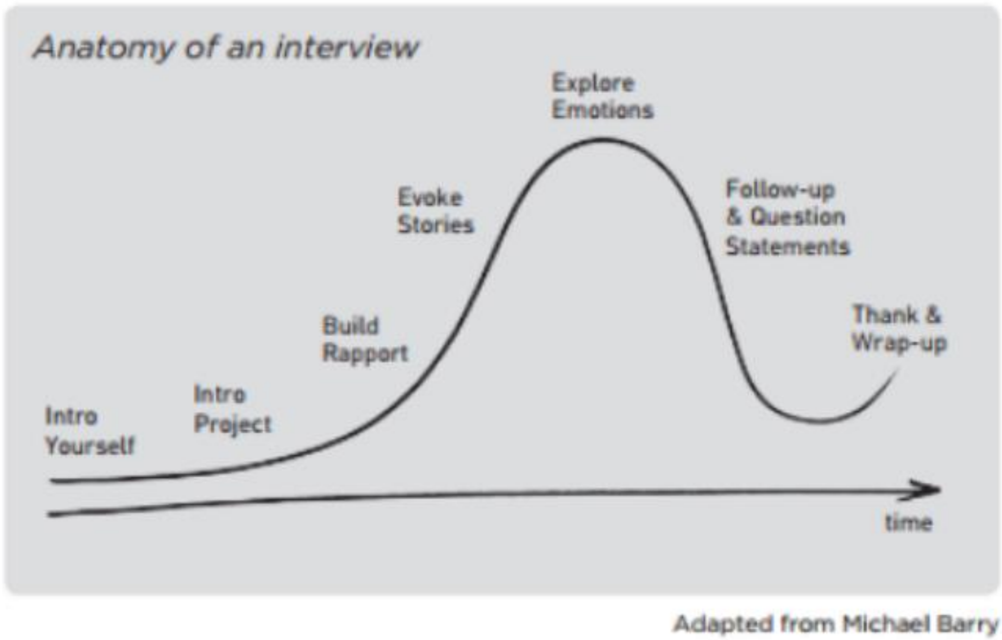

Figure 2: Empathy Interview Format

	Class-wide Surveys	Empathy Interviews
Purpose:	to gather broad data about classroom experiences, preferences, and non-preferences	to develop deep understanding of one or a few individual students' lived experiences
Examples:	Overall, my science class is (select one): • Too difficult • Too easy • Just right The activities that help me learn best are (checkboxes): • Readings • Presentations with notes • Videos • Labs/investigations • Discussions	How are you doing today? What kinds of activities to you love to do, and why? Tell me about a time when you've felt challenged, and why it was challenging. Who are "your people", and why?

Table 1: Classroom Surveys and Empathy Interview Questions

Jacki's Work with Her Students

One high school biology teacher, Jacki, used surveys with her class and empathy interviews to get a better sense of why student engagement in her class was inconsistent. From her survey, Jacki learned a few things. First, that her students enjoyed hands-on labs and would like to do more of them. To her surprise, however, they also highly rated guided notetaking, which she thought the students would have found to be boring. Finally, and to her disappointment, she found that over 80% of her students did not see how their science learning could help them solve problems in their communities. “I was surprised because biology, especially this year, is all about your body”, Jacki said.

For the empathy interviews, which were more time consuming, she chose to be strategic in selecting students to speak with. She found it particularly illuminating to speak with a student who had been challenging to work with throughout the year. “[He said] I want to sit there and take notes and be told exactly what to do for the lesson, but then later on he said I hate it when teachers give super generalized or standardized lessons, I want it to be personalized for my learning.” Jacki wondered how to provide students with structures to support their success while also allowing them the freedom to make choices about their learning.

Photo-journals to support critical science literacy

Based on the students’ feedback throughout the year, Jacki worked to strike a balance between exploratory lab activities that she and her students found more interesting, and the more structured note taking that she found less rigorous, but that the students found safe and predictable. Spring - and the time for standardized testing - was approaching. As Jacki considered different review activities, she hoped to find a way to bridge the gap that the students had expressed between their own lives and the classroom content. She knew that the students loved taking photos on their cell phones and posting to different social media platforms. Soon the idea emerged - what if she encouraged students to use photos of things in their homes and communities to build connections to the classroom?

She developed a photo journal assignment as a way for students to review major topics that would likely appear on the standardized test, while also engaging in new ways of communicating science information to their peers. She provided a list of major topics that students could choose from. Then, students took photos of things that mattered to them, and wrote artists' statements describing the connections to science content they had learned throughout the year. Students who did not have access to a cell phone or personal camera were allowed to look for images during class time. Finally, the students would share their work publicly in a gallery walk format.

The students came back with a wide variety of photos and connections that featured family pets, pollution in the community, and concerns about food justice. Below are some samples of student work. The samples demonstrate how students made connections between topics such as cellular respiration and ecology and tied them back to their own communities.

<table>
<tr><td rowspan="3">Photo: MCAS Topic 2
Due Friday 5/3
</td><td>Biology Topic:</td><td>Ecology</td></tr>
<tr><td>Title</td><td>Immigration and Emigration</td></tr>
<tr><td>Caption</td><td>This shows us how animals could be forced to move from their land because of natural or human causes. When humans, such as me, started to immigrate and create structures that would invade into animals environments- animals had no choice but to emigrate because we would ruin the energy cycle that allowed them to live sustainably. No matter the trophic level all producers, consumers, secondary consumers, or apex predators were forced to move. Duplicating this action might result in the extinction of important organism.</td></tr>
</table>

Photo: MCAS Topic 1
Due Wednesday 5/1

Biology Topic:	CELLS
Title	Cellular Respiration in plant cells
Caption	Plant cells use photosynthesis to convert solar energy into glucose. This is then used in cellular respiration in the mitochondria to make ATP. My image shows a bush with sunlight hitting the leaves. The bush will use this sunlight to create glucose and then use this glucose for energy. Unfortunately, air pollution is a big problem in cities like Boston. Smoke or fog in the air can block out the sun, meaning plants and other organisms that require photosynthesis might not be able to obtain enough sunlight to carry out photosynthesis.

Figure 3: Student Photo-Journal entries

Jacki noted that one student in particular became passionate about food equity in her community:

> She was so hooked from the get-go, from the picture of the Community Garden. It was her community and she got really into a passionate discussion during the gallery walk of well, this isn't equitable that we don't have access to the garden. I didn't expect that, for students to be thinking of oh, that is a problem if I don't have access to fresh food.

In the photo-journal project, the students were given a structure to find the science in their own lives and communities. Rather than being provided with examples from a teacher, they were empowered to make their own connections.

	Pre-Survey	Post-Survey
Question	% Agree or Strongly Agree	
The skills I learn in Biology class can help me outside of the classroom.	71.8%	88%
I use or talk about Biology outside of the classroom.	70%	88%
What I learn in Biology class	16%	80%

can help me solve problems in my community.	

Table 2: Student Pre-Post Survey Responses

When Jacki surveyed her students again at the end of the year. The findings were encouraging - now over 80% of her students expressed that they *did* think that what they learned in science class could help to solve problems in their communities. Jacki considered that in following years, the photo journal project could be ongoing throughout the year so that students built those connections early on and more consistently. The project employed both the principles of Shared Authority and Critical Science Literacy, as students had the choice of what to focus on in their work, and the project supported their understanding of science as something useful for them in their lives and communities.

Democratic Science Teaching - Keeping Relevance and Equity in Mind

The photo journal project supported several of the students in Jacki's classroom in seeing the connections between their lives and the biology content they were learning. However, it is critical to note that part of the reason this worked was due to Jacki's attention to student voice and interests in her particular classroom context. The issue of missing connections was something that emerged from her students and might not be a prevalent issue in another classroom. The table below shows some examples of other ways that teachers have integrated Democratic Science Teaching in their classrooms. Organized by connections to specific DST principles, the strategies also contain the affordances and constraints of the different approaches.

DST Principle	Teacher Strategy	Affordances	Constraints
Student Voice	Classroom Surveys	Provide a broad view of trends, beliefs & preferences in the classroom	Can lead to "majority rule" and further marginalize outlying students

	Empathy Interviews	Provide detailed information about specific students' experiences	Time consuming, care should be taken to hear from differing/marginalized perspectives
	Classroom talk protocols	Provide scaffolds and tools to students to discuss ideas with one another	Takes time and consistency to implement well and students may struggle initially
Shared Authority	Co-generative dialogues	Students and teacher can raise issues around classroom content & culture and collectively decide on action	Requires skillful facilitation and genuine willingness to compromise with students
	Student-developed assessment questions	Students have clarity and choice in the topics and ways they are assessed	Teacher may need to work with students to ensure rigor and relevance
	Student-selected activities and tasks	Can foster engagement and personal investment in classwork	Can be time-consuming to pursue student interests, also needs guardrails against "majority rule" or the loudest voice
Critical Science Literacy	Use of anchoring phenomena	Grounds learning in a real-world context for students	Selecting appropriate phenomena can be time-consuming & results in changes to overall flow of units
	Community-facing assignments & projects	Allows students to engage with and evaluate the needs of their communities and ties to science	Safety and access concerns, restrictions on students' time outside of class
	Exploring bias in science	Allows students to understand science as a process and explore their own biases	Can lead to mistrust and science skepticism

Table 3: Other Strategies for Employing Democratic Science Teaching

The beauty and complication of Democratic Science Teaching is that it reflects specific classrooms with specific students, and it is important to use a variety of methods to ensure that students' voices and preferences are heard. Additionally, teachers must actively solicit the voices of students who aren't the model students, who don't always make themselves heard, and who may represent the minority in the classroom. It is from these students that we as teachers have the most to learn.

Paper 3 References

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Part V: Synthesis & Conclusion

This section will restate the goals and research questions in this dissertation, summarize the findings for each, and outline the implications of this work for future research, teacher education, science teaching, and work toward a system of democratic accountability.

Goals and Questions

This dissertation had three primary goals: to further the development of a valid instrument to measure teaching practices aligned with democratic science teaching, to explore a case of teacher learning and implementation informed by democratic science teaching, and to share with high school science teachers a framework and strategy for implementing democratic science teaching in their own classrooms. The research questions driving this work were:

Paper 1: What is the construct validity of an instrument developed to measure teacher implementation of the DST principles?

Paper 2: What values, attitudes and beliefs are activated over a year as a teacher engages with the Democratic Science Teaching framework? How do those values, attitudes and beliefs inform the teacher's instructional choices?

Paper 3: How can teachers implement the DST in order to bridge the content in the classroom with students' lived experiences?

These research questions are addressed in the respective papers in the dissertation.

Paper 1

Paper 1 outlined the process behind the development of an instrument developed to measure teaching practices aligned with the Democratic Science Teaching principles of student voice, shared authority, and critical science literacy. After a rigorous construct validation process that included expert review and confirmatory factor analysis, it became evident that at least for measurement purposes, but potentially also for purposes of introducing the framework to educators, the three principles might need to be further divided into constructs including student voice *to the teacher,* student voice *between students,* shared authority with the teacher, personal relevance of content to students, and cultural responsiveness to students' backgrounds. The strongest factor model in this paper provides evidence in support of this 5-factor articulation of constructs, and further research into the topic would identify whether teachers responded better to a five-principle organization than a three-principle one. Additionally, Paper 1 identifies democratic science teaching practices as an additional possible measurement that could be used to support a more holistic assessment of teaching and learning. While certainly not intended to be a wholesale replacement for standardized test data as an accountability measure, it is proposed as an additional tool to provide a more complete picture of what is going on in classrooms.

Paper 2

The second paper presented a case of a novice physics teacher who was a participant in a professional learning fellowship built around the DST framework in its original 3-principle presentation. The study explored the ways that engaging with the framework over the course of the year activated democratic science-aligned beliefs and ideas, while exploring the various other contextual factors that activated either complementary or contradictory beliefs. The study found that although there are overarching pressures from schools to teach in ways that are not aligned with democratic science teaching, the framework and participation in the fellowship provided a small amount of "democratic accountability" to implement teaching practices that centered student voice, provided options for student learning, and drew concrete connections between science content and phenomena in students' lives. Overall, the study explored democratic science teaching as one possible framework for accountability beyond the standardized-test driven model. It also suggested that it is important to have clear tasks or outcomes aligned with the DST principles in order to support teachers in their practices - while there was a strong programmatic expectation and supportive structure for soliciting student voice (the use of surveys and interviews), the lack of clear structures and expectations for sharing authority and fostering critical science literacy meant that these were not enacted as clearly in the case.

Paper 3

This paper addressed a practitioner audience with the intention of introducing the DST as a framework and providing an example of how a teacher solicited student voice and developed a classroom photo journal project to bolster critical science literacy. Due to the intended audience of the paper, the focus is heavily on reproducible classroom practices informed by the DST framework. As an artifact from research on teaching, it supports an overall theme in this dissertation - the way that science teachers must make instructional decisions with a lens of traditional accountability. The focal teacher in this study structured her photo-journal assignment as a standardized test review activity. While students were asked to go into their communities to find phenomena of interest, they then were tasked with finding the connections to a scope of science topics dictated by test preparation guidance, rather than having the freedom to explore those phenomena and the rich variety of science concepts that could be related to them. Still, the example shows how a teacher, when held at least partially accountable to the DST principles, found ways to solicit student voice and use that input to shape instruction and design choices in the classroom.

Synthesis & Implications

Together, the papers of this dissertation present implications for the way that the principles behind Democratic Science Teaching are articulated; for teachers, teacher educators or teacher leaders who are interested in supporting DST practices in their schools and communities; and for the development of tools and programming to support a vision of democratic accountability.

Implications for Articulating the DST Principles

The DST model at this time is presented as consisting of three overarching principles: student voice, shared & transformational authority, and critical science literacy. There may be utility in organizing the ideas behind DST in this way. However, in the development of the survey instrument for the DST professional learning, it became clear that these three principles contained in themselves sub-principles. For example, student voice could be further broken down into student-to-student voice and student-to-teacher voice, and for critical science literacy, into cultural responsiveness and personal relevance. In the teacher cases, this was further supported as the teachers developed separate structures for supporting student-student voice (such as procedures for student feedback & class discussions) than they did for supporting student-teacher voice (surveys and interviews). The teacher featured in the paper was able to find a way to bridge science content and phenomena of personal relevance to her students but did not identify ways to make the classroom a culturally responsive place overall - again suggesting that these might be distinct principles. It may be helpful to further refine the DST framework model for educators, particularly when it comes to defining strategies and interventions.

Implications for Teachers & Teacher Educators

This study also presents implications for practitioners. For teacher educators who may want to support more responsive, social-justice oriented classrooms, the DST may present a helpful guiding framework for science teachers. As previously explored in the introduction, science teachers often struggle to see how science can be taught in a culturally responsive way. The DST provided an organizing framework for the case teachers to think about how to make the science classroom a place that empowers students to use their voice and make choices, and to see how science connects to their lives. Additionally, the structures explored in the cases, particularly student surveys, interviews, phenomenon-driven units, and photo-journal projects provided concrete examples of how to foster the DST principles. Teachers & teacher educators could consider how to apply these structures to their own contexts, and to potentially further develop structures to support shared and transformational authority in the classroom, as that was an area of difficulty for the case teachers. This leads into the overarching accountability structure which places a high value on learning specific concepts in science rather than allowing for student exploration and choice.

Implications for Democratic Accountability

Across both of the case teacher papers, the specter of traditional accountability cast a consistent shadow. As high school teachers in a state where passing the science standardized test is part of the graduation requirement, there is pressure on them and their students to learn specific facts and ideas. Teachers who otherwise felt an affinity for the ideas of democratic science teaching struggled to authentically share authority with students, knowing that in the end their academic success would be heavily dependent on test scores. Still, these cases provide some supportive structures for what the tools of democratic accountability might look like. The instrument developed in paper 1 represents one possibility for measuring not just what information is learned, but *how* instruction happens. The student surveying and interviewing practices in papers 2 and 3 could provide structures for science teachers to make instructional choices along with students rather than for them. All of these small pieces can contribute to the development of holistic accountability systems that foster an informed and democratic society. This contributes to a society where all people have access to science understanding and can take a critical perspective on who is doing science and for what purposes, and where communities that have been systematically marginalized and excluded from decisions about how science is used will be empowered to speak out.

Conclusion

The impact of accountability policy that very narrowly focuses on standardized test scores is well documented. Although standards and test-driven accountability was intended to support equity by identifying areas where students were not being served, “opportunity gaps and the resulting achievement disparities were not closed merely by emphasizing higher standards or by holding teachers, schools, and districts accountable for raising students’ test scores" (Beyond ESSA 3.0, p.4). In science classrooms specifically, rather than supporting rigorous, meaningful classroom instruction, traditional accountability has “necessitated fleeting coverage of science topics and classroom pacing guides, [and] constrained teachers and schools” (Linn et al, 2016, p. 549). This “conservative” science instruction privileges rote memorization of facts, following procedures, and minimal opportunities for students to make personal meaning of science, or connect it to their lives and interests (Stroupe, 2014). This has resulted in many students opting out of science during their K-12 experience as they feel that their funds of knowledge, means of expression, and identities overall are not welcome in science spaces (Regan & DeWitt, 2015; Tawfik, Trueman &Lorz, 2014). Furthermore, this pedagogy does not accurately represent science in practice, which is not a stagnant body of facts, but is a highly collaborative, social, and even creative endeavor - a “dynamical system of undertakings driven by complex interactions among social structures, knowledge representations, and the natural world” (Fortunato et al, 2018, p.1). It also does a disservice to science as a discipline as diverse ideas and voices that would challenge and potentially spur innovation are excluded even before they can be heard (Harding, 2015). Therefore, if governments and schools want to support a more diverse population of participants in science, as they claim they do, (Sass, 2015; National Science Foundation, 2019) science classrooms must shift, and accountability structures too must shift in support.

This dissertation puts forth the Democratic Science Teaching framework as one possible component of a different kind of accountability. A small group of teachers, when introduced to the framework and provided with structures to implement, was able to identify possibilities for expanding student voice in the classroom and building opportunities for students to apply science learning to phenomena in their world, and utilize creative practices like photo-journals to identify the science behind the things that are important to them. With the added accountability of their professional learning community, they were committed to this work even as they also needed to meet the requirements in place from their school and state requirements. Tools like the DSPA instrument introduced in Paper 1 could be used by school leaders and professional learning leaders to both communicate expectations for specific, DST-aligned classroom practices and to assess the presence of those practices in classrooms.

As the Beyond ESSA 3.0 report states, it is not likely that federal policy will shift its own frame for accountability in the very near future, although many other groups have called for a "reimagined" system (2023, p. 7). The focus from the federal level does still remain somewhat focused on a narrow interpretation of "what" is being taught. However, state, district, and school leaders can make internal decisions to place efforts in supporting a different "how" of teaching. It is important to emphasize that this work and these papers do not endeavor to add another layer of accountability to teachers' plates without any support, and although one instrument was presented, it is not recommended as a tool to use without consideration and possible modification to the local context. Rather, school communities of leaders, teachers, students, and families should come together to identify what instructional practices are important for fostering curiosity and engagement among students. Science classrooms in particular, places where student questions and sensemaking should be integral to the function of the classroom, and indeed are already elevated in the current national standards (NGSS Lead States, 2013), would benefit especially from this input. Widespread critical science literacy for all students is a key part in the development of a healthy and empowered society.

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