Title: Transforming Science Teaching for Equity and Justice by Teachers and Researchers Working Together

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Abstract

With the urgent call for supporting science teachers to promote equity and justice through their daily work of teaching, there is a growing need for better understanding how science teachers come to engage in transformative teaching and learning that is equitably consequential. In this participatory design research project (Bang & Vossoughi, 2016), we created a professional learning context in which high school chemistry teachers engaged in a pedagogical imagining (Gutiérrez & Calabese Barton, 2015) by leveraging their teaching experiences, knowledge about students and communities, values, and concerns to create powerful learning contexts for Latinx and multilingual students from immigrant, low-income families. Drawing upon the perspective of learning as making and sharing of the world interwoven with making and sharing of selves (Warren et al, 2020), we analyzed teachers' participations and discourses to examine teachers' making and sharing that were equitably consequential. The findings illustrated three critical moments of teachers' making and sharing where: (a) the teachers collectively developed shared pedagogical goals toward transformative learning while formulating agency, (b) the teachers and the researchers came to design a creative stoichiometry unit where students use chemistry to make their community better, and (c) the teachers came to be committed to being 'intentional' in their relational work to create a welcoming and safe learning environment using concrete pedagogical strategies. The analyses point out three design features of the professional learning context that were associated with the teachers' consequential makings: (a) the use of a conceptual tool (i.e., 'design principles'), (b) the power of "what if" discourses, and (c) creating a space for collective learning. Recommendations for designing professional learning context toward transformative teaching and learning are discussed.

Key words: inservice teacher learning, social justice and equity, participatory design research, science education

Introduction

> *"And that's kind of what I struggle with as well. You know, high school students, they get it. You know, they understand what's going on right now and I was just thinking like, if we were in school right now, I think there would be some protests in the school, which is great. But yeah, but what does that look like in a chem - you know, teaching stoichiometry. I don't necessarily know, maybe it is coming back to sharing their projects and having conversations about those projects. I don't, I don't know that's what I was thinking about as well, like how - what would it look like in the classroom." -Adriana, a 10th grade chemistry teacher, European-American, female, June 5, 2020*

Adriana is a 10th grade chemistry teacher who works in a public high school in the Southwest of the United States that serves predominantly Latinx students from linguistically and socioeconomically disadvantaged communities. She is one of many science teachers who deeply cares about her students and is willing to go above and beyond to support her students' learning and well-being in her classroom. She is also one of many science teachers who struggles to figure out what it means to promote equity and justice in their daily work of teaching ("what does it look like in a chemistry classroom?"). As illustrated with Adriana's comments, this difficulty of connecting disciplinary teaching and learning (for instance, "stoichiometry") to a commitment to equity and justice is an important problem of practice that many science educators are wrestling with, especially at the secondary level.

Over the last three decades, numerous promising pedagogical approaches, frameworks, and curriculum or strategies have been developed to help teachers like Adriana to promote equity and justice through the work of teaching. Some examples of well-received frameworks are culturally relevant pedagogy (Ladson-Billings, 1995) or leveraging funds of knowledge (Moll et al., 1992), rightful presence (Calabrese-Barton & Tan, 2020) framework. And the list continues to grow. Despite the increasing knowledge about science learning, equity, and promising pedagogical resources, such powerful pedagogy is not a current norm at most schools in the United States, and minoritized students' struggles of relating themselves to sciences continue. There is little agreement among researchers about what it means for secondary science teachers, like Adriana, to bring equity and justice in their daily work of teaching. There are few well-grounded theories that explain how teachers like Adriana learn to provide powerful learning experiences for minoritized students in secondary science classrooms.

In this paper, using participatory design research (PDR) (Bang & Vossoughi, 2016), we explore four high school chemistry teachers' participation and discourses in the context of a year-long research+practice partnership to understand their learning to teach for transformative science teaching and learning. Our design experiment rests on the premise that "change in the individual involves change in the social situation itself" (Engerström, 2008 cited by Gutierrez & Vossoughi, 2010, p. 101). We were interested in examining the forms of learning that emerge in and through partnering between high school chemistry teachers and researchers toward transformative social change. Bang and Vossoughi (2016) posit that transformative social change involves "the interweaving of structural critiques with the enactment of alternative forms of here-and-now activity that open up qualitatively distinct social relations, forms of learning and knowledge development, and contribute to the intellectual thriving and well-being of students, teachers, families, and communities" (p. 175). In the context of this partnership project, transformative social change that the teachers and researchers intended to make involved the

enactment of alternative forms of science teaching and learning that open up new social relations, forms of learning, and support the intellectual thriving and well-being of Latinx and multilingual students who have been historically marginalized in science classrooms, based on structural critiques of settled norms, expectations, and practices of teaching and learning at schools. The following questions guided the analysis:

1. How did the professional learning environment become organized around the participants' transformative social change making?
2. How did high school chemistry teachers and university researchers engage in new subject-subject and subject-object relations toward social change?
3. How did high school chemistry teachers exert their agency to disrupt the settled norms and practices of science teaching to create engaging and empowering learning contexts for minoritized students?
4. What were the tensions or dilemmas emerging in the process of working toward transformative social change and how did teachers and researchers navigate tensions?

This study is significant because it sheds light on teacher learning toward social changes with new theoretical and methodological approaches in the field of secondary sciences. This study will provide practical implications for designing and facilitating teacher learning for social transformation by articulating the theory behind the design of professional learning activities.

This article is organized as follows. First, we synthesize prior research on teacher learning for equity and justice in the field of mathematics and science education, focusing on the assumptions, key constructs, and teacher changes attended by the researchers to recognize teacher learning. We discuss how our study challenges and extends the existing body of research. Next, we present our conceptualization of teacher learning for transformative disciplinary teaching and learning that guides the research design and analysis of this study. After describing the study context and method, the findings section illustrates three critical moments of teachers' making and sharing that were consequential to minoritized students' experiences with sciences in chemistry classrooms. We conclude this article with the discussion of three design considerations for creating professional learning contexts toward transforming teaching and learning at schools.

Literature Review: Teacher Learning for Promoting Equity and Justice

Our review of literature was guided by the following four questions: (a) What theoretical and methodological approaches do researchers draw upon to study teacher learning in light of promoting equity and justice through mathematical and/or science teaching? (b) How do researchers conceptualize the notion of disciplinary teaching that promotes equity and justice? (c) What are the desirable changes that researchers look for to identify teacher learning for equity and justice? (d) How have researchers designed professional development programs to support teacher learning for equity and justice? We were committed to consider a variety of authors and their backgrounds to involve multiple voices and cultural backgrounds in understanding teacher learning for equity and justice. The review was conducted in the following procedure. First, we conducted keywords search in databases (Google Scholar and ERIC) and ten peer-reviewed journals (*Teaching and Teacher Education*, *Science Education*, *Journal of Research in Science Teaching*, *Journal of the Learning Sciences*, *American Educational Research Journal*, *Cognition and Instruction*, *Journal of Teacher Education*, *Journal of Mathematics Teacher Education*, *Journal of Science Teacher Education*, *Urban Education*). The key words that we used were 'teacher learning and social justice', 'teaching for social justice and equity', 'equity oriented science/mathematics teaching', and 'professional development for justice and equity.' Through

these keywords search, we identified a total of thirty-four articles. In addition, we identified additional thirteen published studies from the reference list of the selected articles. We read through the abstracts of all forty-seven, and selected a total of sixteen articles for close review using the following criteria: (a) empirical studies that address mathematics and science teacher learning, (b) focused on either elementary or secondary education, (c) teacher participants were in-service teachers, (d) published in peer-reviewed journals over the last 30 years (1990-2020). Close review was conducted focusing on (1) assumptions about promoting equity and justice (including the theoretical construct as the basis of those assumptions), (2) data sources, (3) teacher changes observed by the researchers, and (4) proposed theory to understand teacher learning for equity and justice. For the sake of space, we synthesize five themes emerging from the articles that studied in-service science or mathematics teachers in secondary education (K-6 to K-12)--the focus of our investigation. Table 1 presents the details of each study.

--Insert Table1 about here--

The five themes

First, there are relatively few empirical studies that examine either mathematics or science in-service teacher learning toward the goal of promoting equity and justice. Out of the forty-seven articles that were selected, twenty-two were related to professional development programs based-research focused on pre-service science or mathematics teachers, sixteen investigated science/mathematics teachers in-service (eighth in elementary and eight in secondary education), six investigated in-service science teachers for special education, and three articles focused more on student learning than what teachers learned from professional development programs. The fact that almost half (twenty-two out of forty-seven) of the published studies focused on pre-service science/mathematics teachers can be explained through the current deficit-based view that portrays elementary school teachers as responsible for a crisis in science education (Gilbert & Byers, 2017). This pattern opens up a venue for contributing to the apparent emerging research on mathematics/science in-service teachers toward equity and justice, as well as calling for a shift from deficit- to asset-based research on teacher learning.

Second, according to the eight articles that studied in-service mathematics or science teachers in secondary education, the researchers tend to conceptualize teacher learning for equity and justice holistically focusing on consequential social transformation. Rosebery, Warren, & Tucker-Raymond (2016) and Brown and Crippen (2017) conceptualize teacher learning based on *adopting a responsive teaching or pedagogy in order to work with students' diverse ways of making sense of the world*. This view involves that teachers shift from deficit-based to asset-based orientations toward students' sense-making. These orientations help teachers in dismantling normative views of ways of talking, knowing and being in science classrooms in order to teach science as a heterogeneous, creative, and multivoiced human activity. Planas and Civil (2009), Louie (2017), and Felton and Koestler (2019) proposed to conceive teacher learning for equity and justice as *a process of empowerment that enables teachers to take responsibility in disrupting, altering, and change the game of traditional classrooms' culture of exclusion*. Having power is a means to improve people's lives and to promote social changes. Educational transformations (as a type of social change) can be generated from reframing mathematics teaching and learning in ways that expand students' opportunities to learn. On the other hand, Bartell (2013), Wager and Foote (2013), and Brenner, Bianchini, and Dwyer (2016) understood teacher learning for equity and social justice as *a lifelong undertaking process of enculturation into a community of practice where they can confirm, deny, or expand their identities*. A possible way for teachers to be immersed in a community of practice is through

doing actual research and being involved in processes of inquiry, action, reflection about areas for improvement and/or transformation in the science classroom. Therefore, the challenge for teacher researchers is to determine issues in their teaching practice in the science classroom where action must be taken to achieve equitable mathematics pedagogy.

Third, the eight published studies draw upon frameworks related to sociocultural theory, broadly speaking, to conceptualize key dimensions or constructs in order to empirically examine teacher learning for equity and justice. The constructs were 'interpretive power' grounded in Ball & Cohen's (1999) work (Rosebery, Warren, & Tucker-Raymond, 2016), Darling-Hammond (2002)'s equitable pedagogy model that consists of self, society, students, and school (Bartell, 2013), Durkheim's view of culture (Louie, 2017), Goos and colleagues' zone theory grounded in Vygotsky's work (Felton-Koestler, 2019), the concepts of teacher research and educational equity (Brenner, Bianchini, & Dwyer, 2016), 'praxis and Holland's figured worlds' (Wager & Foote, 2013), Ladson-Billings' and Gay's definitions of cultural responsive pedagogy (Brown & Crippen, 2017).

Fourth, there were four observable characteristics attended by the researchers in order to empirically examine desirable teacher changes. Those were: (1) knowledge, beliefs, views, and practices; (2) goals of teaching; (3) framing and attunement; and (4) identities. The most popular characteristics attended by the researchers were *knowledge, beliefs, views, and practices* (see Brenner, Bianchini, & Dwyer, 2016; Brown & Crippen, 2017; Felton-Koestler, 2019). For example, Felton-Koestler (2019) glanced at shifts in teachers' teaching beliefs and views about the nature of mathematics, students' abilities, and how children learn mathematics, as well as shifts in teaching practices that the teachers proposed based on their beliefs and views about mathematics education. On the other hand, there were two studies that attended to *the goals of teaching* to recognize desirable teacher changes (i.e., Bartell, 2013; Planas & Civil, 2009). For instance, Bartell (2013) examined how teachers progressively negotiated the goals of both mathematics and social justice in their practice. There was a specific interest in identifying if the participant teachers of the study reconciled or kept isolated these goals in their practice. Talking about a different characteristic, two published studies considered *framing and attunement* as indicators to identify teachers' learning for equity and justice (see Louie, 2017; Rosebery, Warren, & Tucker-Raymond, 2016). An example of this is Louie's study (2017), which examined how teachers framed the nature of mathematical practice or activity (i.e., what it means to do mathematics) and the nature of mathematical ability. Then, the author focused on any alignment that existed between teachers' instructional practices and their frames. Only one study (Wager & Foote, 2013) looked at *teachers' identities* to identify teacher learning. Wager and Foote (2013) studied how teachers' identities within three figured worlds were changing over time. These figured worlds were: standards-based mathematics; multicultural education; and equitable mathematics pedagogy. The authors examined if teachers confirmed or expanded their existing identities, or deny possible emerging identities.

Fifth, there were some notable patterns with respect to the goals and the main design features of the professional development programs implemented by the researchers from the eight published studies. In terms of the goals, the goals of teacher learning are characterized in three ways: (a) developing an understanding about what it means to teach mathematics/science for equity and justice; (b) expanding ways of noticing and understanding students' sense making; and (c) transforming instructional practices toward equitable and just forms of teaching mathematics/science. The most predominant goal was to develop a conceptualization about what it means to teach mathematics/science for equity and justice (see Bartell, 2013; Felton-Koestler,

2019; Planas & Civil, 2019; Wager & Foote, 2013). For instance, Felton-Koestler (2019) aimed to support teachers in developing deeper understandings of how students' relational thinking and issues of equity and diversity played out with students' performances and more generally in their whole classroom. There were two studies (Louie, 2017; Rosebery, Warren, & Tucker-Raymond, 2016) that designed their PD based on the overarching goal of broadening teachers' ways of understanding students' sense making. Rosebery, Warren, & Tucker-Raymond (2016) had the main purpose of supporting early career teachers' in making relationships to students' repertoires of ways of thinking, doing, and talking in sciences in order to create expansive learning spaces in their classrooms. According to the third trend, two studies (Brenner, Bianchini, & Dwyer, 2016; Brown & Crippen, 2017) designed their PD based on assisting mathematics/science teachers in transforming their instructional practices toward equitable and just forms of teaching. An instance of this type of PD goal is Brown and Crippen's study (2017). The authors designed a PD that aimed to support high school life science teachers in developing culturally responsive, reform-based science teaching knowledge and practices while constructing rigorous instructional materials aligned with their students' experiences.

In terms of the design of the PDs, we examined the length, the main activities, and the main relationship between researcher and participants in the PDs. Among the eight published studies, four studies (Bartell, 2013; Brown & Crippen, 2017; Felton-Koestler, 2019; Rosebery, Warren, & Tucker-Raymond, 2016) lasted 6 months, three (Louie, 2017; Planas & Civil, 2019; Wager & Foote, 2013) had a length of 1 year, and one of these eight studies lasted two and a half years (Brenner, Bianchini, & Dwyer, 2016; Brown & Crippen, 2017). In terms of the activities that the participants engaged in during the PDs, the most common activities were reading and discussion sessions about texts related to equity and justice generally, and mathematics/science teaching for equity and justice specifically. The second most common activity was analysing teaching classroom cases in light of equity and justice constructs (Bartell, 2013; Brown & Crippen, 2017, Rosebery et al, 2016; Wager & Foote, 2013), and co-designing, implementing, and analyzing either a mathematics/science lesson or a series of four lessons based on equity and justice orientations (Bartell, 2013, Brown & Crippen, 2017; Rosebery, Warren, & Tucker-Raymond, 2016). In terms of the relationship between researchers and teachers, two studies (Bartell, 2013, Brown & Crippen, 2017) showed 'subject-subject relationships' where researchers and teacher participants interacted and worked collaboratively towards the design, implementation, and analysis of mathematics/science equity and justice-oriented lessons; while the rest of the studies seemed to have a more traditional way of working where the researchers ('subject') delivered the knowledge to the participating teachers ('object').

Expanding the existing body of knowledge

In summary, the review reveals that there are relatively few empirical studies that focus on mathematics/science in-service teacher learning for equity and justice in secondary education. Not only the scarcity of studies is a call for our attention, but also the deficit-mindset that prevails in the way that teacher learning is investigated. Also, it was found that teacher learning can be conceptualized based on teachers broadening their capacity of understanding students' sense making, empowering themselves to take transformative actions that can disrupt the normative ways of teaching and learning mathematics/science to move toward transformative disciplinary teaching and learning, and experiencing the process of enculturation within a community of practice that enables them to expand their identities as equity-justice committed educators. However, an integral definition that encompassess all these dimensions has not been proposed and employed yet. There is a need to understand teacher learning from a

multidirectionality perspective; i.e., teachers are internally transformed in the process of learning about teaching for social changes, but they also actively transform the contexts where they participate.

With respect to these theoretical standpoints, we identified that multiple theoretical frameworks aligned with sociocultural theory were used as lenses to study teacher learning for social justice. Teacher learning is seen as a complex social activity that requires particular interactions and specific contexts to emerge; however, if we relate this theoretical view of teacher learning to the observable characteristics that the researchers identified to characterize teacher learning, the framework does not always well align with the observable characteristics attended by the researchers. For instance, Felton-Koestler (2019) proposed the zone theory (a theoretical construct derived from the Vygotsky zone of proximal development) to understand teachers' own beliefs and views about mathematics and students' disciplinary ideas. These indicators of teacher learning are seen as something that is 'stored' in the conceptual ecology of teachers. We propose that a more coherent alignment between sociocultural theory and the observable characteristics that are empirically identified is required to better understand a teacher not only as an internal process, but also a collective activity that has to be with the types of interactions and actions that teachers exhibit in relation with particular contexts.

Regarding the goals and features of the professional development in the consulted published studies, participants are engaged, in a relatively short period of time (approximately six months) in individual work that support them in increasing their knowledge and skills toward teaching sciences for equity and justice. The relationship between researchers and teachers that is prevalent in these types of professional settings is subject-object; i.e., researchers ('subject') move teachers ('object') forward in their learning through delivering information. This finding is a call for attention to offer alternative ways of teacher learning focusing on learning as a collective, instead of focusing only on individual changes.

Building upon and expanding the existing body of research, this study intends to examine the forms of learning that emerge in and through partnering between high school science teachers and university researchers toward transformative social change. Employing a participatory design research approach, this study paid particular attention to the features of the setting that organize and mediate professional interactions and changes as a collective in addition to individual changes. Our ultimate goal is to offer an alternative way to understand science teacher learning based on an asset-based approach that includes teacher-researcher-context as a crucial triad for learning ecology.

Theoretical Framework

In our pursuit of new forms of science teaching and learning at schools that is equitably consequential, we first discuss equitable and just science teaching theorized by critical scholars in the field of science education. Building upon the research on disciplinary teaching, we conceptualize science teacher learning for equity and justice as 'making and sharing toward transformative learning' and discuss how this conceptualization guides the research design and analysis.

Teaching Science Equitably and justly

The prevalent mode of teaching and learning at schools, in general, and teaching and learning of sciences specifically, has been criticized by numerous scholars (e.g., Bang et al., 2012; Gutiérrez & Rogoff, 2003; Ladson-Billings, 1995; National Academies of Sciences, Engineering, and Medicine, 2018). Space and time at school are often strictly controlled and

circumscribed to specific moments and places. Science teaching mostly stays relatively disconnected from learners' other worlds. There has been growing critique toward formal education that fails to value and build on the cultural resources of learners and the communities of which they are part (Bang et al., 2012; Moll et al., 1992; Warren et al., 2020). The teaching of sciences at school is often focused on making students' 'understanding' or 'mastering' canonical scientific knowledge, which emphasizes Western, Eurocentric ideology, values, and ways of knowing. The mode of teaching that focuses on canon-building positions students as passive receivers, instead of active sense-makers, critical problem solvers, and action takers. The framework of decolonization posits canon building as "as a process of exclusion, erasure, and onto-epistemic violence that nullifies presences-assumed-not-to-exist (Morrison, 1989) in the form of white imaginings of African Americans (Gates, 1984) or settler imaginings of Native people (Smith, 2012; Vizenor, 2000)" (Warren et al., 2020, p. 277). Science classrooms are often configured as spaces where only one 'voice' is privileged, the one related only to 'scientific' thinking.

Despite the growing consensus about the limitations of the conventional mode of science teaching and learning at schools, a deeply context-dependent nature of instruction makes it difficult for researchers to present *the* mode of science teaching and learning that *is* equitable and just (Carter & Darling-Hammond, 2018; Cohen, 2008). Instead of searching for the mode of equitable and just science teaching, researchers attend to frameworks or sensitivities that guide teachers' principled and adaptive pedagogical decision-making in local contexts.

In this study, we draw upon the notion of onto-epistemic heterogeneity to re-imagine transformative disciplinary learning (Warren et al., 2020). The notion of onto-epistemic heterogeneity rests on two key ideas. First, knowing and being are inextricably tied. This sets a stark contrast of the prevalent mode of teaching and learning sciences at schools, where disciplinary knowledge is located in authoritative sources (e.g., textbooks, teachers, or scientists) and knowing and learning is isolated from the lives of students and their everyday experiences. Second, liberatory education ought to be deeply rooted in the pasts, presents, and futures that sustain and imagine multiple values, purposes, and arcs of human learning (p. 274). This also sets a stark contrast with the existing practices of schooling where typically singular value, purpose, and way of being good at science is proposed as the right or the norm. Accordingly, this framework of onto-epistemic heterogeneity calls for imagining radically different horizons of possibility for knowing and learning.

The framework articulates three sensitivities that help teachers to engage in re-imagination of disciplinary teaching and learning toward a commitment to equity. First, *multiplicity* attends to the heterogeneity of knowledge, ways of knowing and learning. Teachers need to consider multiple ways of knowing in a discipline as well as students' diverse ways of knowing, doing, and being. It involves actively recognizing and celebrating multiple ways of doing sciences. It also involves actively leveraging students' diverse sense-making repertoires. Second, *horizontality* calls for deliberately facilitating the movement of repertoires of practices between school science classrooms and other spaces where students live and participate. For example, teachers can create a learning context where students explore events, problems or concerns that matter to them or their communities while leveraging both their funds of knowledge and school science knowledge. The last sensitivity that guides the reimagination of science teaching and learning is *dialogicality*. A student's discursive interactions in every moment, including both academic and non-academic, with teachers and other members in the

classroom learning community do affect the ways in which students think, do, act, and feel in the classroom learning environment.

Conceptualizing Learning to Teach Science Equitably and Justly: Making and Sharing of the Worlds and Selves Toward Transformative Science Learning

The research on science teaching, learning, equity and justice suggests that learning to teach science for equity and justice involves teachers' engagement in re-imagining disciplinary teaching and learning (Warren at al., 2020) or 'pedagogical imaginary' (Gutiérrez & Calabese Barton, 2015), instead of reproducing the settled norms, expectations, and practices of science teaching and learning. During the process, teachers ought to recognize and problematize the dominant mode of teaching that promotes canon building as the main goal of learning sciences at school. Teachers ought to see its epistemic violence or epistemic injustice (Fricker, 2017) to both teachers and students, in particular from non-dominant communities. Teachers come to be aware that they can either contribute to perpetuating injustice and inequity through the canon building or disrupt the development of onto-epistemic just-centered science classrooms.

Grounded in sociocultural and critical perspective, in this study, we view learning as "the making and sharing of the worlds woven with the making and sharing of selves" (Morrison, 1993; Smith, 2012; Warren et al., 2020). This conception of learning foregrounds one's actions to make better worlds through both 'making' *and* 'sharing' with others. In the context of learning to teach science equitably and justly, science teachers as learners make and share their worlds while simultaneously making and sharing themselves toward transformative teaching and learning. For example, teachers might take a risk of developing and using a justice-centered curriculum that deviates from what they normally do in classrooms. Teachers might come to reconstitute their stories of 'what it means to learn and be good at sciences' while engaging in new practices. Teachers might come to initiate the conversations with the colleagues in their department to decolonize the curriculum. Teachers might come to position and be positioned by others as someone who cares about students' well-being and academic success, someone who is willing to learn what it means to promote equity and justice, someone who is willing to open, challenge, and be challenged about settled practices of teaching and learning at schools. In theory, teachers' making and sharing of their worlds woven with making and sharing themselves can be seen by closely examining the deliberate *actions* that they take in social, professional, and pedagogical contexts, the *relations* that they (re)form, and their *stories* about problems of practice, student learning and success. Teachers can mobilize and exert their agency to disrupt the reproduction of dominant practices or discourses deeply ingrained in their daily work of teaching, and seek out a new pedagogy that attends to and builds upon minoritized students' diverse experiences, identities and feelings.

Method

In this participatory design research (PDR) project (Bang & Vossoughi, 2016), the aim of the design experimentation was co-constructing professional learning contexts in which high school science teachers and researchers leverage students' rich cultural assets and funds of knowledge to create engaging and empowering learning environments in their own classrooms. Attending to the notion of 'politicized trust' (Vakil et al., 2016), we (university researchers) worked side-by-side with 'teacher researchers' to democratize our partnership activities. Not only did the teachers participate in the professional learning activities, but they also participated in various decision-makings as co-designers of their own learning experiences. The teachers and researchers made decisions about research activities collectively, such as what data the research team should collect, when this data should be collected and how to collect the data.

Setting

The partnership activities took place in one school district in Southern California. This partnership grew out of the prior research conducted in one high school over the past four years. A total of seven high school science teachers (four chemistry and three physics) from two high schools, four science education researchers (one faculty, one postdoctoral researcher, and two graduate students), and two scientists who played the role of consultants participated in the project. Five out of the seven teachers worked at a Title I school where 78% of the students were Latinx, 17% were English Learners, and over 67% of students were eligible for the free and reduced lunch program. In this study, the analysis focuses on the participation and discourses of four chemistry teachers in one Title I high school and one researcher who facilitated the conversation.

Participants, Relations, and Positionality

The participants of this study were three chemistry teachers, one student teacher, and one researcher (the first author). Three teachers, Adriana, Leslie, and Anita (all pseudonyms), were White women. Mary and the researcher were non-native speaking immigrant Asian women. Adriana was the most senior teacher who had ten years of teaching experiences at the time of this study. While assuming the role of the department chair, she mentored both Leslie and Anita when they were hired at the school. Both the school principal and people in the district office spoke highly about Adriana. Adriana participated in various leadership meetings and district-initiated activities, such as designing NGSS-aligned curriculum, on behalf of the chemistry department at the school. Her classroom was orderly and well-managed. She focused on providing explicit and clear expectations about the tasks.

Leslie had five years of teaching experiences. She received her teaching credential from the university under the supervision of the researcher who taught the secondary science methods courses. Leslie and the researcher had a long term relationship cultivated over the five years since Leslie participated in the researcher's prior studies. This long-term relationship helped the researcher to form this partnership with the school district, and started this partnership project.

Anita was a new teacher who just completed her first year of teaching following the student teaching at the same school. Anita worked at elementary schools as a reading and English language development specialist for three years before receiving her science teaching credential. Anita became a close friend with Leslie since her classroom was right next door. Anita's parents immigrated from Italy, so Anita had many relatives living in Italy.

Mary was a student teacher placed in Leslie's classroom. Mary was taking a class (secondary science methods course) taught by the researcher at that time.

Tools and Resources

One tool that was used throughout the partnership was what is called, 'the five design principles.' The principles were: *make it matter, support sense-making, build a welcoming community, attend to race, language, and identities, and disrupt power hierarchies* (see the detail in Author and other, in preparation). As a conceptual tool for mediating teachers' interactions, the design principles presented pedagogical goals or intentions translating key lessons from the research on equitable and just science teaching and learning. For example, numerous prior studies showed that minoritized students likely engage in science meaningfully when they can deeply relate to the tasks (e.g., Birmingham et al., 2017; Calabrese Barton & Tan, 2010). This lesson was translated into 'make it matter.' The design principles were introduced by the first author on the very first day of the project, and used by both researchers and teachers throughout the year to unpack the 'why' of the practices. This conceptual tool was

complemented with various records of practices, such as student work, exemplary curriculum materials and assessments, etc.

Professional Learning Activities

In this project, the participating teachers and researchers engaged in two cycles of professional learning activities throughout a year (one in the fall, the other in the spring). Within each cycle, teachers participated in the activities of: (a) experiencing sciences as learners, (b) co-designing a unit storyline, selecting a focal phenomenon or problem, and designing final and initial assessments, and key learning activities, and (c) co-planning and enacting one lesson while visiting the classroom together, and (d) analyzing student artifacts.

Experiencing sciences in a new way as learners ('modeling'). On the first day of summer PD, teachers were invited to become 'students' in a 9th grade biology class. The facilitator (the first author) presented a model unit where participants explored the recent measles outbreak and anti-vaccination group's protest in the local community. The design of this model unit was informed by three sensitivities of the onto-epistemic heterogeneity framework. As 'community scientists,' the participants were tasked to research the community's questions and concerns regarding the measles outbreak and the purpose and safety of vaccines (e.g., "How do vaccines work?", "What might happen to an individual who doesn't get vaccinated?"), conduct the investigation and find solutions, and make a recommendation to the County Department of Education Office regarding the issue of mandatory vaccination at schools. Through this model unit, participating teachers got the sense of how student and community concerns could be brought to the center of science learning, how students' interest, concerns, or questions could drive the activities, and how students' diverse cultural practices and home languages could be leveraged with a skillful use of multiple forms of instructional and assessment tasks (e.g., written assessments and letters or artifacts that communicate the findings with the community and the Department of Education) throughout the unit. The 'why' of the practices reflected in the unit design was discussed in detail after this 'modeling' activity while introducing the five design principles.

Co-designing student experiences in a focal unit. The major activity of the PD throughout the year was co-designing student experiences in the focal unit. The teachers as disciplinary teams (physics, chemistry) were tasked to create engaging and empowering learning contexts by framing the unit using a phenomenon or problem that mattered to students. Using the phenomenon or problem, the teachers developed a unit storyline and designed multiple forms of assessments that expanded what it means to learn or be good at science as well as ways of showing one's learning (see the detail in Author & other, under review). The teachers designed a sequence of learning activities that helped students to expand their initial thinking. Throughout the co-design activities, each team of teachers shared their unfolding unit design ideas and exchanged feedback multiple times. Teachers' pedagogical goals and intentions were communicated by selecting a few design principles that each team decided to focus on while building the unit storyline and explaining the reason why. The team provided feedback in relation to the selected design principles.

Co-planning, co-teaching, and analyzing the teaching. The teachers participated in co-planning and co-teaching activities during the on-site professional development. The team selected one lesson of the co-designed unit, and co-planned one lesson in the morning of the PD day. The co-planned lesson was enacted in the teachers' classrooms once or twice during the day. The team collected and analyzed student learning artifacts from the co-planned lessons. At times, this activity was replaced with teaching video analysis. For example, the chemistry

teachers wanted to use their PD day for generating curriculum materials of the co-designed unit. The classroom visit and observation were replaced with the analysis of the teachers' teaching video.

Analyzing student artifacts. Upon the completion of the unit, teachers were guided to take a look at various student learning artifacts collected by the research team multiple times. The artifacts were students' responses to: (a) science identity survey ('Is Science and Me?' see Author and others, 2019), (b) exit ticket, (c) student experience survey, (d) assessment tasks, and (e) interviews. The research team presented a summary of student responses or selected samples strategically to draw teachers' attention to particular problems.

Data Sources

Multiple sources of data were generated through observation, survey, artifact collection, and interviews throughout the year. For the analysis of teachers' making and sharing toward transformative teaching and learning in contexts, in this study, we analyzed the following sources of data: (a) the video recordings of professional development meetings (about 36 hours), (b) artifacts generated for or from the professional development meetings (e.g., planning document, meeting agenda, slides, snapshot of the meetings, teacher-generated artifacts), (c) the interview transcripts with three chemistry teachers (about 6 hours), (d) field notes from 15 classroom observations (5 lessons x 3 teachers = 15 lessons), (e) teaching artifacts of the co-designed unit (e.g., hand-out, slides), and (f) student learning artifacts produced from the co-designed unit.

Data Analysis

Grounded in the conception of learning as making and sharing of the world interwoven with making and sharing of themselves toward transformative learning, the analysis focused on examining how high school chemistry teachers came to engage in making and sharing of the world and themselves that were consequential in expanding minoritized students' opportunity to learn in science classrooms. Two researchers (the two authors) participated in the data analysis for about seven months. One researcher was an Asian female who designed and facilitated all the meetings as a PI of the project. This researcher leveraged her deep relationship as well as contextual and historical knowledge about the school, district, and participants to look at the data. The other researcher was an Mexican male who did neither participate in any of the partnership activities nor had any relationship with the participants, which helped to generate a balanced interpretation about the data. Any disagreement was discussed in the bi-weekly meetings until the two researchers reached the agreement. The following describes the details of the process.

Generating video logs. First, we generated video logs while watching the recordings of the professional development meetings. The video log described things that happened in detail while chunking interactions as events (e.g., the teacher launches the task, facilitating one group's conversation). The video logs were shared with each other highlighting a few 'interesting events' during the meetings at the early stage of the data analysis.

Identifying the episodes that illustrated teachers' making and sharing that were consequential. We were interested in identifying a few key episodes that showed teachers' *consequential* making and sharing. By consequential making and sharing, we referred to the professional interactions that directly affected the expansion of minoritized students' meaningful disciplinary engagement in the classroom. We first looked at the field notes generated from the 15 observations of teachers' lessons in the co-designed unit, and student learning artifacts. This analysis of student learning helped us to identify key features of learning experiences that

appeared to facilitate Latinx students to form new and transformative relations with chemistry and people in the classroom (see the analysis of student learning of this co-designed unit in Authors & other, in preparation). We went back to the video logs and identified a total of seven episodes that appeared to be consequential. The questions that helped us to select the key episodes was, "What were the set of professional interactions or conversations during the PDs that directly affected the ways in which students experienced chemistry in the classroom?", "What might have happened in the classroom if this set of interactions didn't take place during the PDs?" Each episode in the videos was transcribed, and then developed as a vignette using additional data sources (e.g., artifacts produced from the meetings). The vignette described the details of the settings as well as the professional interactions.

Analyzing the key episodes. Guided by the research questions, we analyzed each of the vignettes with attention to: (a) the ways in which the setting became organized around the participants' transformative social change making, (b) the relations between the teachers and researchers manifested through positioning, assumed roles, and/or status, (c) the ways in which the teachers exert their agency to disrupt the settled norms and practices of science teaching, if any, and (b) emerging dilemmas or tensions. In our analysis of emergent forms of learning in this context, we paid particular attention to critical historicity, power, and relationality (Bang & Vossoughi, 2016).

Findings

We present three episodes that illustrate the teachers' making and sharing of the world and themselves toward transformative forms of science teaching and learning. Each of the episodes highlights critical moments of teachers' making and sharing that were consequential on Latinx and multilingual students' experiences with sciences in classrooms.

Episode #1: Developing shared pedagogical goals that matter to the teachers

This first episode shows the processes in which the teachers collectively developed shared pedagogical goals toward transformative chemistry learning while formulating transformative agency. During the whole day professional development (PD) on January 13, 2020, two groups of teachers--three physics and four chemistry--engaged in the co-designing activities of one upcoming unit. The chemistry team's focal unit was stoichiometry. While opening the meeting, the researcher (the first author) drew the teachers' attention to the five big posters hanging on the wall that stated each of the design principles. The researcher invited the teachers to choose one or two design principles that they wanted to focus on while co-designing their units. Each teacher wrote down the reasons why they chose the design principle(s) on post-it notes, and then put the post-it notes on the big posters. Once everyone's notes were on the posters, the researcher initiated the conversation:

> The researcher: So let's briefly share what kind of teacher you want to be, what kind of unit you want to build upon, and what kind of feedback you need from us to help you to get to the point where you want to be. So, anyone who would like to start the conversation? Like, 'Here is the principle that I really want to focus on today as I am building this unit.'
>
> Adriana: [looking at everyone on her table to start talking] We are just saying that we are doing Stoichiometry as a unit, and *it is very difficult to get students to relate to stoichiometry*, and then to make it matter to them.
>
> The researcher: Yes, that's the million dollar question
>
> Adriana: Yes

The researcher: Stoichiometry matter? [laughing] Great! I will keep that in mind. We're focusing on that.
Adriana: [smile] Correct [other chemistry teacher said 'Yeah!']
The researcher: Would you like to go around the table?
Anita: Sure! I wanna build off that. I think I agree, I think we are all pretty much in agreement that making stoichiometry matter to our students is a huge priority, and also I'm just thinking back to teaching it last year, and kind of supporting, like the second principle 'supporting sense making' that *I think it's super important to me as well, because I want them to like care enough to start like thinking like absolutely out of the box since stoichiometry is not something that is...that they see it like directly related to their lives*.
The researcher: So it seems to me that if you want to help students in sense making in the unit of stoichiometry, you gotta think about creating some task or activity where kids can use stoichiometry to explain and justify something, if you want to go to the sense making, right? Because stoichiometry itself is not the idea, it is a wonderful tool that we can use to make sense of a lot of things. So yeah, that will be great. I am happy to support. Mary?
Mary: I did put [my post-it notes] on 'making it matter' and 'sense making' [posters] as well. Explaining the sense making part, I put that instead of having them just repeat all stuff, *I want [my students] to understand why they need other stuff and then add other stuff. I want them to justify each step and understand why they are doing it rather than just doing it because that's what they usually do*.
The researcher: It can be great if we can see a lot of 'why' in their thinking. Great! Leslie?
Leslie: I would say that part of the motivation of choosing this unit was that this is the unit that kind of sucks the motivation of the students, and a lot of...any amount of care about chemistry is really a slump, and so I think by f*ocus on 'it,' not like a task to do, like Mary was saying, and then make it applicable after this unit and after this year. So kids can see it as a tool that they can use. I am hoping not to see them want to die*. [everyone laugh]
The researcher: Yes, I remember one of Leslie's ideas that we shared in the very first meeting is kids love science, and we don't want to lose that in the stoichiometry unit. So yeah, that will be wonderful. Like you know, some of the criticism that is offered by science educators, science teachers keep saying 'Oh, just hanging there, hanging there, this will be useful some days in your life.' But for a lot of kids that's too far. So how we are going to help them see its value in the moment when we are doing that. It requires a lot of our thinking because we have to build the task in a very careful way. Oh right! We have a very challenging task today, but we will get there!
All the teachers: [excitingly laughing together]
The researcher: Go chemistry team!
All the teachers: [Laughing]

In this episode, the four chemistry teachers came to develop shared pedagogical goals that they intended to accomplish with their students in the focal unit. Two goals were *making stoichiometry matter* and *support students' sense-making*. There are a few notable patterns in the

participation and discourses that shed light on teachers' making and sharing toward transforming science teaching and learning in classrooms. First, the conversation was framed by the researcher as making and sharing their identities as science teachers ("share what kind of teacher you want to be, what kind of unit you want to build upon"), instead of discussing the goal of this unit. By doing so, teaching science was re-framed as becoming a particular kind of a science teacher. The teachers shared their personal stories, experiences, and feelings, while explaining why they wanted to focus on a particular design principle in this particular unit with this particular group of students. Although the concerns expressed by the teachers varied, what they shared included topics and ideas that mattered to them *personally* (e.g., "it's super important to me"). They connected their own problems of practices to two shared pedagogical goals that would guide the making of students' experiences in this unit.

The other notable patterns in this episode was that the teachers and the researcher co-constructed the problems of conventional ways of teaching stoichiometry while building the collective agency for transformation. The four chemistry teachers brought different experiences and concerns to the spaces. The general framing of the problem ("it is very difficult to get students to relate to stoichiometry") deepened and specified as teachers built upon and expanded the initial idea while sharing their feelings. Interestingly, the problems noted by teachers in teaching this topic were consistent with the broader patterns and critiques by critical scholars. The teachers were concerned about: doing school without deep intellectual and emotional engagement (Mary, Leslie), disconnecting students' own identities, interests, and concerns with the discipline (Adriana, Leslie), losing interest toward the discipline (Leslie, Anita), and disconnecting the learning of chemistry in the present moment with their lives in the future (Leslie). With this sharing of individual concerns, the four teachers began formulating their collective agency to commit themselves to taking deliberate transformative actions in order to better support students in their classrooms.

One tension emerging from developing the shared goals of the focal units was that some design principles, such as attending to race, language, and identities, were rarely selected by the teachers. Throughout the whole year, the chemistry and physics team co-designed a total of four units (two units per each disciplinary team). There was only one time that the principle of 'attending to race, langage, and identities' was selected by the teachers. On one hand, giving teachers choices of selecting the goals that they wanted to focus on appeared to cultivate their agency. On the other hand, this design seemed to limit the teachers to attend to and address some important aspects of designing transformative science learning at schools. This dilemma posed the question of when and how to draw teachers' attention to the 'un-selected design principles,' without the researcher positioning as the authority to 'tell' the teachers what they ought to attend to. Later that year, the researcher brought student identity survey data that showed the diversity of students' racial, ethnicities, and linguistic backgrounds to the meeting. The researcher drew the teachers' attention to 'race,' and facilitated the conversation with the topic of, 'What does it mean for you to attend to race as a science teacher?" (an afterschool PD on January 27, 2021).

Episode #2: Changing the learning of chemistry from 'solving a chemistry problem' to 'using chemistry to help people'

The second episode illustrates the processes in which the teachers and the researcher came to design an innovative and creative stoichiometry unit where students use chemistry to make their community better (see a sample of student work produced from this unit in Appendix A; see the analysis in Authors in preparation). This making of transformative student learning

was associated with two things: (a) disrupting the existing structure of teaching chemistry at schools that is organized by isolated topics, and (b) engaging the re-imagination of a liberatory form of learning through the discourses of "what if."

Disrupting existing structure of teaching chemistry at school. After setting the two pedagogical goals (i.e., making it matter, and supporting sense-making), the four chemistry teachers began discussing the unit storyline and an overarching question that would set the context of students' inquiry. One teacher, Leslie, opened the conversation with the idea of combining two chemistry units (thermodynamics and stoichiometry), instead of teaching them separately as they normally did. This idea of disrupting the existing structure of teaching chemistry stemmed from the shared goal of supporting students' sense-making. Leslie, and other teachers, recognized that it was difficult to support students to make sense of anything within the current topic-centric, compartmentalized structure of chemistry curriculum. They thought that the phenomena of 'heating up or cooling down,' a topic typically addressed in the thermodynamics unit, could be used as a context for students to calculate the mass of materials needed to make a chemically powered device. The following are interactions from teachers while planning key activities of the stoichiometry unit:

Leslie: The original idea-ish is combining thermo with stoich. So there are some applications.
Adriana: Correct.
Leslie: So the idea is, let's figure out something that you actually care about, that's important, you need to either heat up or cool down, or keep it hot or cold. Because like the generic ice pack kind of like sounds like '-ing' (boring)
Anita: uhumm (agree)
Adriana: [noting her head multiple times, signaling that she agrees]
Leslie: What do they *really* care about?
Adriana: But, really can they choose anything?
Leslie: They could.
Adriana: Depending on, do you want to heat up anything? then you can adjust the amount of heat…?
Leslie: I kind of like that. As they choose something that you'd want to heat or cool something that they care about. I like that.

This idea of combining two units was well received by the chemistry teachers because they were looking for ways to support students' sense-making and making stoichiometry matter to their students. It is important to note that historically, chemistry (and all other sciences) has been taught at schools as a list of isolated topics (e.g., chemical reaction, thermodynamics, stoichiometry, etc.). This topic centric structure of school sciences privileges the voices and values of scientists over students' concerns or experiences, representing what were perceived to be important to learn perceived by the science community. While wrestling with the two shared goals that they committed to, the teachers came to realize that following this topical order of teaching chemistry did not enable them to support students' sense-making and provide experiences that students feel matter. They collectively decided to get rid of the settled practices of organizing student learning in the topical order as they worked toward *their* goals.

Openly challenging one another and engaging in the re-imagination of a liberatory forms of learning through the discourses of "what if"

With the new frame of combining two units, the teachers formulated an essential question that set the backbone of students' experiences in this unit. The question generated by the teacher was, "*How can you design a device to make something reach the perfect temperature?*" The four teachers liked this question because they thought students could use stoichiometry to calculate the change in enthalpy per gram of product needed to adjust the temperature of a system. Although this framing of the question might afford students' sense-making opportunities, the learning of chemistry was focused on solving a chemistry problem at school rather than making meaningful connections to students' everyday lives, experiences, and concerns as members of the community (cf., horizontality). There was little room for students to generate 'multiple possible answers' and leverage diverse sense-making repertoires--a key principle for equitable science teaching and learning (cf. multiplicity, epistemic heterogeneity). Moreover, the opportunity for students to cultivate their transformative agency appeared to be low with this framing of the essential question.

As illustrated in the episode below, the way of framing this question was challenged, interrogated, and eventually modified through the conversation. The revised question was "*How can we design a chemically powered heating up or cooling down device for people who do not have access to electricity?*" Later, as teachers piloted this question in their classrooms, the question was launched along with a conversation about, "What if we could use chemistry to make a difference in our community? What are some situations where you would want to heat something up or cool something down without using electricity? Who might you want to make this device for? What do you think the device should be made out of?" (classroom observation on February 6, 2020). With this new framing of the unit essential question, students were positioned as someone who would use chemistry to help people with limited resources. The following conversation illustrated how the teachers came to make this critical shift by re-framing the learning of stoichiometry from 'solving a chemistry problem' to 'using chemistry to make a difference':

The teachers were casually talking after they made an agreement about the essential question. When the researcher joined the group, the teachers excitedly talked about their essential question. After listening to the teachers' explanations about this essential question written on the poster paper, the researcher initiated the conversation.

The researcher: I'm still thinking about this idea of 'making it matter' and I wonder, is there any way that we can connect this 'amount of use' to sustainability at all?

Leslie: I would say that, maybe I'm worried to do sustainability in the fall, and then sustainability now [winter] followed by wildfires [in spring]. I feel that [students] are going to get burned out on [that]. Should they care about the world? Yes! But, they are already like a lot of eye rolls about sustainability three weeks in.

The researcher: That's a valid point. Let's go to a little bit more identity or personal connection. So let's think about it.

Leslie: [after a few seconds of silence] I had the thought about '*what if* your power went out.' I mean *for* people who don't have electricity.

Adriana: I would say, when you are camping? But not everyone has the experience of going camping at all.

The researcher: No.

Leslie: I kind of like that idea 'without electricity.'

Adriana: Can we have an earthquake between now and then? [laugh]

Leslie: I'm going to guess that most of our CP [Comprehensive Preparation] kids have experience living without electricity.
Adriana: We had an earthquake over the fourth of July.
Leslie: I'm not thinking of earthquakes.
Adriana: What are you thinking?
Leslie: I'm saying that I would argue that most of our CP kids have experience living without electricity, without electricity for a certain extent of time.
Adriana: Probably, but…
The researcher: So what I'm hearing, what I am seeing here is that you are framing the unit around problem-solving, not around understanding the phenomena, which is totally fine. So you can bring an engineering kind of idea in this unit, because if this is a problem where you don't have electricity and you need to heat up, like how could you do that? Then, the first question that I have is what kind of materials are available to heat up something? That's to me, a first question, just the materials, things. Depending on the choice of the materials, how could we generate the heat? Do they even consider bringing the idea of collision of the molecules to think about it? That is another part of the problem solving that they need somewhere in their thinking that they have to do that. Then how much of each material do you need to generate the heat? These questions come to my mind.
Adriana: Because we'll need to give them options [i.e., students choosing the 'perfect' temperature], because I just think they don't know what chemicals heat up or cool down.
The researcher: Yes. So, are there any chances for kids to be in a situation like that? Or who will be in that kind of situation like living without electricity? Having a limiting access to electricity? Or under what conditions either in an earthquake or homeless people? Who is living outside? There is another way that we can tie in? This morning I was listening to NPR that LA has a huge homeless population, fifteen percent of people are so cold in winter.
Adriana: We have the largest population of homeless in the country
Leslie: Any kind of energy. When we do fire evacuations, people are in shelters. When we see the massive earthquakes or floods, or tsunamis, or whatever. All these disasters.
Adriana: The volcano, the wildfires, these disasters in New Zealand…
Leslie: I would say honestly. Part of me is like I don't know if it is relevant for them individually. I would say that our population, our kids are awesome because they are pretty compassionate.
Adriana: Yes
Anita: Yeah
The researcher: It's a crazy idea, but *what if* I can design the things that I talked about to make it warm, a small little pack or something. I want to give these things to the people who are living outside in the cold winter.
Adriana: That's what I wanted to say. To design a device for, or to ship to people in Australia who people who need it to, or to the more local
Leslie: Okay, let's keep words [bring back the paper that had the first essential question]
Adriana: Or a natural disaster

Leslie: What part of this [essential question] do we change? [look around the people's face while referring to a specific part of the essential question on the paper] All of it? Do we like the chemically powered, or to take that out? [everyone was looking at the paper]
Anita: I like that
Adriana: I like it
The researcher: I like that
Leslie: I feel like
Anita: I feel like it roots it in something
Leslie: Device to…
Adriana: Don't say use the microwave or ice
Leslie: Can 'you' or can 'we'?
The researcher: Can 'we'
Adriana: Yes
The researcher: So is it about the design, the heat up…?
Leslie: Device. What?
The researcher: Can we design a chemically-powered device for people…?
Adriana: Do we need to say that ['for people'] though in the essential question?
Leslie: I mean, it is encrusted in something that it matters to; it's up to the board the whole thing?
Adriana: Yeah, but in the periodic trends, we didn't put the word 'sustainable' up there, you know?
The researcher: So what we are doing right now is framing the problem. So in this unit what the things are that we try to do. *You need to decide if it is a problem of solving chemistry, or a problem of helping people*. So it's up to you, you want to frame the problem of helping people using chemistry; that is the problem we are working on, and using this stoichiometry idea to figure out how to help people who need a little bit of heat, let's say.
Adriana: Yes. That's still where we are saying the helping aspect of it. I'm just concerned when we say, when we ask the question, how to answer the essential question in our summary table, then they go back to that aspect of, if we say helping the homeless, and then you are not helping them. But they can do more like...do you know what I mean?
Mary: This might be a little off tangent, but if we go for helping homeless people, instead of making the sales pitch, *what if* it is like a fundraising or something like that?
Leslie: We can move something, yeah!
The researcher: Yes, what are the things that we can do? It is not just homeless people who need this kind of heat device outside in these kinds of situations, like earthquake. All people can use this device.
Leslie: Yes, that's why I'm not saying only 'homeless people,' but 'people who don't have access to electricity.'
The researcher: I like 'the access'
Leslie: Do we want to say electricity?
The researcher: How can we design a device that provides…
May: To heat up or
The researcher: Yes, to heat up and cool down for people…

Leslie: What about chemically-powered heating or cooling device?
The researcher: Yes!
Anita: Magic! We did it!
Leslie: For people who don't have access to…
The researcher: Electricity?
Leslie: I like the idea of electricity.
The researcher: Yeah, that is kind of 'no electricity'
Adriana: *What if* it is not available? Because not having access?
Leslie: I like this idea because you can brainstorm when people don't have access to electricity. If they are in a country that does not have infrastructure; hello, Puerto Rico. In an emergency they don't have access to electricity.
Adriana: So it is not about 'when' instead of 'for'. For when people don't have access to

This episode illustrates the teachers' and the researchers' collective making of chemistry learning where students were positioned as someone who could make a difference in their community using chemistry. The revision of the initial, essential question came with the team's deep contemplation of how they could make stoichiometry truly matter to this particular group of students who lived in Southern California, a community suffering from increasing occurrences of massive, natural disasters, such as wildfires and earthquakes, and the increasing homeless population. The teachers' wondered 'what might my students feel and what truly matters here-and-now.' This perspective drew their attention to students' identities and everyday experiences in this particular geographical, social and historical context. The teachers attended to difficult life situations that the majority of their students had outside of school ("most of our CP students have experience living without electricity for a certain extent of time"). The team also attended to the world that their students were living in at the moment, highlighting concerning events locally and globally (i.e., the increasing number of people living outside during the winter, increasing environmental disasters associated with climate change and its impact on people's lives). In light of the collective goal of making it matter, the teachers re-framed the learning of chemistry from 'individually solving a chemistry problem' to 'using chemistry to help people collectively' (i.e., how can *I* design a device *to make* something reach the perfect temperature → how can *we* design a device *for people* who do not have access to electricity?). One notable pattern in this episode was the use of a discourse move, 'what if' as a deliberate action towards the making and sharing of a liberatory form of chemistry learning. Both the researcher and the teachers used 'what if' or 'what if-like' discourses several times during this exchange. This discourse move seemed to open up a new possibility for the participants' re-imagining of teaching and learning in the stoichiometry unit, as evidenced by the critical shift in the framing of learning chemistry in this unit.

There are several tensions or dilemmas emerging in the processes of teachers' making of transformative science learning. The first tension emerged when the researcher posed questions about the essential question that the teachers already agreed upon. Up until the researcher joined the conversation, the teachers were satisfied with the question that they formulated by combining the two units. The researcher challenged the teachers and bid them to consider designing transformative learning towards making a better world using chemistry, beyond just doing chemistry at schools. It appeared that having shared goals, such as 'making it matter,' helped the participants to navigate the power laden relationships without establishing the power hierarchy of the researcher as 'the knower' and the teachers as 'the learners.' All the members, including both

the teachers and the researchers, leveraged their own knowledge, experiences, and expertise as co-designers of student learning experiences toward the shared goal.

The second tension emerged as the teachers tried to find a way to establish a meaningful connection between a science task and a group of students who brought a wide range of experiences. The team brainstormed various situations when people do not have access to electricity, such as camping, earthquake, evacuation, wildfire, etc. One dilemma that the participant encountered while wrestling to make it truly matter to their students was that none of the experiences could be universally relevant to every single student. This dilemma led the team to frame an open-ended question where students could generate their own individual connections and a sense of mattering by identifying people who they care about and exert their agencies--designing a chemically powered device for people who do not have access to electricity.

The third tension emerged as the teachers debated between 'for people' and 'in a certain situation.' Framing the central task as 'for people' signified humanizing the learning of chemistry by foregrounding the people who are impacted by, as well as students' feelings and compassion towards people. Framing the essential question as 'when' signals the changeability of the situation--anyone can be in such a situation and the situation can be changed. This was important to the teachers given the potential emotional burden of some students who might have difficult life situations and live without electricity at the moment. All these intentions and concerns surfaced as the team discussed and revised the essential question.

Episode #3: Supporting teachers to be intentional in facilitating relational work during instruction

The third episode illustrates the processes in which the teachers came to be committed to being 'intentional' in their relational work to create a welcoming and safe learning environment using concrete pedagogical strategies. This critical making was associated with: (a) co-constructing an image of 'ideal' teaching and learning through collective imagination, (b) describing and noticing the discrepancies between the ideal image and the actual classroom interactions in their own teaching videos, and (c) collectively setting the goal based on pedagogical reasoning about the sources of students' struggles. This episode was situated in about two hour long video analysis activity during the whole day PD on February 25, 2020. For the sake of the space, we briefly describe the key interactions in a chronological way in order to show *how* the teachers came to be attentive and committed to be intentional in their relational work. Some key features of participation and discourses that shed light on the teachers' making are highlighted in this narrative.

Opening: Co-creating the space of teachers' collective learning. The teachers began implementing the co-designed thermo-stoichiometry unit from the first week of February, 2020. The researchers (faculty, graduate students, and undergraduate research assistants) had filmed three teachers' lessons about once a week upon the teachers' invitation. Although the teachers used the same co-designed curriculum materials, not surprisingly, there were notable differences in the type and nature of interactions observed across the three teachers' classrooms. Adriana's instruction was clear in delivering expectations and presenting information, and students tended to follow the direction in an orderly manner in a relatively dry environment. Anita's instruction was filled with encouraging and emotional language in a lively environment, such as "beautiful, people", "amazing idea" when the teacher typically asked a question and students gave an answer. In Leslie's instruction, there were rich conversations and humor between the teacher and students or among students . Students shared their ideas and stories of their personal experiences

at home or their communities. The researcher (faculty) noted in her field note, "*Each teacher has different relationships and ways of interacting with students. In some ways, this is reflected in the languages that they are using. This is also evident in the ways in which they begin the lesson, and visit each small group. I think the classroom interactions really reflect each teacher's perceived goals and identities. I wonder to what extent I can challenge, disrupt or expand them*."

It was about two and a half-weeks after the teachers started teaching the co-designed unit when the whole day PD on February 25 took place. The original plan of this whole day PD was visiting each teacher's classroom and observing each other's classroom practices. Instead, the teachers wanted to use the PD day for planning the rest of the unit. Based on the teachers' decision, the emerging plan for the whole day PD was to analyze three teachers' teaching videos, and support teachers' planning of the thermo-stoichiometry unit.

The day began by sharing each other's feelings in the moment. This followed by co-constructing the norm of collaboration, and then setting the day's goals together. The researcher (the first author) shared the eight norms generated from prior research, and invited the teachers to share the norms that they liked, or wanted to use as a reminder, or suggest any new norm. The meeting agenda was introduced as "draft." The researcher invited the teachers to set the goal together, she said: "I would like to make a plan together. This is my draft agenda. Could you take a look at the agenda? I would like to set the goal. By the end of the day, what will make *you* happy? I want to help you to get that goal, but we need to be really clear what we want to accomplish today." As illustrated below, the teachers were continuously invited to participate in various decision-makings throughout the PD, such as what to focus on when they watched the teaching videos, whose videos they wanted to watch, and how to adjust the goals.

Before viewing the teaching videos: co-constructing an image of 'ideal' classroom through collective imagination.

Collectively deciding the focus of watching their teaching videos: 'making it matter.' The researcher launched the video analysis activity by inviting the teachers to share the aspect of practices that was important to *them*. The researcher said, "I want to focus on the things that are important to you. Is there any particular aspect of practice that you wonder about? Something that you want to improve?" After a few seconds of silence, one teacher, Leslie, proposed to focus on the 'making it matter' design principle. She said, "one of our biggest goals for this unit is making it matter...I knew that when we were designing this unit, our struggle with this previously was that the kids didn't know why we were doing this stuff. So, really contextualizing each lesson, how does it connect to the bigger picture? Why are we doing this? Why is it important for you to learn this?" The other teachers expressed their strong agreement with Leslie's idea either verbally or gesturing (e.g., nodding the head). All three teachers expressed their positive feelings about their own teaching at this pre-viewing stage. Adriana said, "Things are going *so much better* [this year] than previous year as there is a context that we can relate it to. [all the teachers agree, Yeah!] But this video might show otherwise [everyone laughing]." The team collectively decided to look at their teaching videos with the lens of 'making it matter.'

Co-constructing a frame of reference (the meanings of making it matter) to look at teaching videos: 'coming to see connections.' The conversation began with the researcher's question to the teachers, '*What matters to you?*' After one teacher made a joke, "the crappy TV show that I watch?", the teachers, two graduate students, and the researcher all shared the things that mattered to them: "family, that matters the most", "the people whom I care about, their health", "friends whom I can go cry", "socializing with people, having a chance to talk to people and making connections", "community." After everyone's sharing, the researchers noted, "It is

interesting that nobody mentioned chemistry." The teachers paused a second and smiled while looking around one another. Noting that chemistry at schools doesn't necessarily tie directly to the humans or families, the researcher posed the next question, "We want to make it [chemistry] matter to our students. *When are kids developing this sense of mattering?* Based on your own experiences, is there anything like, 'That doesn't really matter to me [initially], but at some point, it *came to* really matter?" This question generated a lengthy conversation as each of the teachers shared their personal stories about when and how science *came to* matter to them at a certain point in their lives. Adriana thought that students come to see mattering "if they have a sense of, I want to make the world a better place" highlighting that mattering is related to social change. Leslie shared her personal story of how chemistry all of sudden became her favorite subject during her high school year. After finishing her freshman year, Leslie participated in cancer research at the Fred Hutchinson Center in Seattle. She said, "It was the first time that I saw, literally, what you do in your class is what they literally do in real life." Leslie thought students might come to develop a sense of mattering if they "*see the connection*" between what they learned at school and sciences in the world that have an impact on people's lives. Anita shared her personal stories during her high school year, highlighting *how learning sciences at school empowered her as it helped her to navigate personal struggles*. Her mother was diagnosed with thyroid cancer, and coincidentally she was taking a biology class where she learned human body systems. Anita vividly remembered she actively participated and asked questions to her teacher. All the information that she learned from her biology class was meaningful to Anita because it helped her to understand what is going on with her mother. She said, "That was like the first time I felt super connected to sciences." Anita felt "completely out of control" when her mother was diagnosed with cancer. Learning sciences through her biology class at that time, however, "gave [her] some control back to be able to say, okay."

Through this sharing of deeply personal stories, the teachers and the researchers formulated the shared understanding that developing a sense of mattering had to do with *'connections'* that students are making between the things that they learn in class and what is happening in their personal lives and outside the world. The conversation then shifted to the role of the teacher in facilitating students to develop a sense of mattering in chemistry classroom. In response to the question of "*what do you see as the role of teacher?*" The three chemistry teachers articulated various ways in which teachers could support students to form a sense of mattering while they built upon one another's ideas:.

Anita: I think just from what we all said, that connections to something in your lives is really what makes science matter to you. So *I felt like our role as a teacher is helping them see those connections*. I don't know you guys, but when we were doing Pantry Station, my kids came back, "Why didn't you tell me how many calories in Cheetos?" [everyone laughing] I don't eat the serving size, I eat the whole bag, now I know. So it is funny they are recognizing like I am not eating the serving size. I am eating the whole bag. I am eating this many grams and calories. That's kind of superficial like 'mattering' to them. It is at least in the step in the direction that they are making connections. So *our role is like facilitating, helping them to make connections and maybe they can bridge*.

Leslie: *I think also, explicitly providing the opportunities and directions too.* 'Okay, where do you see this connection in your life?' Cause I don't think this is something, unless you specifically ask, 'Do you see a connection?' this doesn't connect to anything. Probably don't think that direction?

Adriana: I think we inherently try to make that connection. We are also adults who had life to learn. But our students aren't? We don't explicitly ask those questions.

Leslie: But, I think that that habit I guess, like seeing the connection. That's kind of what we do in science, I guess. [agree] That's where all are the connections here. So training them to look for it. I think, one, makes it more matter, and two, think more scientifically.

The researcher: I completely agree with everything that we talked about here. But there are a couple of questions that we gotta ask to ourselves. *Is it even possible to help kids to make those deeper connections if we do not know kids' life, what do they care about? Is it possible to help kids to make those connections if we are not explicitly providing for students to think about these two things together?*...In addition to that, a lot of kids have a lot of stuff going on in their own lifes… who knows, they might have a family who are in a difficult situation...Having students to develop a sense of mattering, I feel super important at the same time very challenging. It is not about just talking to them, 'this matters.' We need to be really mindful and deliberate in terms of what we talk and how we talk. And who gets to talk and what we are going to talk about when we ask them to do. I think a lot of things are going on. I think it is worthwhile unpacking a little bit. A little bit more intentional when we do our work. This is what I would like to do together with video analysis.

In this episode, the teachers co-constructed the meaning of 'developing a sense of mattering' as 'seeing the connections' as they shared and unpacked their own personal experiences as science learners, and related it back to their struggles with their own students as science teachers. In other words, the teachers were making connections among their own experiences, the pedagogical goal of 'making it matter,' and concrete teaching practices that they could do as teachers. Furthermore, each of the teachers brought different stories and they were collectively formulating a far more complex view on what it means to help students to develop a sense of mattering. During this whole conversation, the researchers constantly revoiced, rephrased, synthesized, and challenged by drawing the teachers' attention to something that they did not mention.

Collective imagining the ideal classroom: "What do you expect to see in an ideal classroom?" The last part of the conversation before viewing the teaching videos was formulating the image of the classroom where students feel chemistry matter. The researcher prompted, "Okay, let's imagine a beautiful classroom situation where kids really develop this sense of mattering. Then, *what do you expect to see in this class from teachers and from students?* " The first image that the teachers immediately came up with was "students listening to one another." The teachers unpacked the meaning of "true listening" in comparison to just "hearing" while describing various observable cues, such as students' body language, eye contact, body posture. The second image shared by the teachers was "responding." Leslie said, "I think when you are truly listening, you are going to respond to it in some ways, either to ask some further questions or share how your ideas are similar and building on that." The third image shared by the teacher was "kids might like to do stuff", "if it matters to them, they are not like skirting around the task." The researcher further pressed the teachers to imagine the ideal classroom interactions focusing on talk moves, saying "In terms of talk move, what kind of talk do you expect to see?" Instead of typical talk patterns dominated by the teacher, all the teachers said they would like to see classroom talk where students build upon one another's ideas (e.g.,

teacher talk-student talk-student talk-student talk-teacher talk-student talk…). Lastly, the researcher prompted the teachers to think about the images of the teacher in such an ideal classroom, saying "What might the teacher look like in an ideal situation?" The teachers shared the ideas of: "asking probing questions" (Anita), "modeling behaviors that you want to see" (Adriana), "facilitating such a way that you are prompting kids to build on each other. So, if they are not going to do that for themselves, okay, structuring that, so they are responding to each other, rather than" (Leslie). While discussing the ideal image, Adriana shared her dilemma of facilitating conversation while maintaining the orderly classroom, "How do you do that in the classroom when you have 10 different groups? If you want that individual true conversation within the group yet you are modeling it. It is a fine line in between managing the class and managing the group discussion. It's just a struggle at times." The other teachers expressed their empathy through nodding and verbal responses. While acknowledging this inherent complexity of teaching at schools, the researcher turned into the viewing of the teaching videos.

Viewing the video: just describe. The viewing of the video was framed as "describe, notice, and understand, not judge." The researcher said, "How do the teacher help students to develop a sense of mattering? That's what we are exploring. Let's just describe what you saw, what you noticed." Each of the teachers, positioned as 'a researcher,' took a role of documenting what they saw focusing on one aspect of teaching: (a) talk pattern, (b) what students talked, and (c) what the teacher talked or did. They watched three segments of about 7-8 minutes long teaching videos, the same lesson using the same curriculum materials, in the order of Adriana's, Anita's, and Leslies's. After watching one teacher's video, everyone took a turn and "described what I saw" and then moved to the next video. As for Adrinana's video, the teachers described the talk pattern as "a lot of, just back and forth, teacher talk-student-talk-teacher-talk-student talk." What being said by the teacher was described revealing the emphasis of delivering expectations and management:

> "There was a lot of, see, logistics, being very clear about expectations for the day, what to expect, and directions for the task...classroom management or expectation. So every time when she said, "you need your phone away" this is what I wrote down...describe the context for the task, prompting for ideas and revoicing student responses. Directions and expectations, and questions for individual responses."

The next video was Anita's. The talk pattern was described as, "a lot of student-teacher-student teacher (talk). And then in the middle of small group discussions, there were mostly student talking. I couldn't hear everything but I am sure there were a lot of students discussing." What being said by the teacher was described highlighting the teacher's effort to make connections--taking chemistry in school out of class, connecting to the experiences with the prior units:

> "Recapping what we've done so far, explicit about taking it out of class, so taking chemistry in class out of class. Framing the day's task, asking questions about previous class experiences, directions, probing, re-phrasing the prompt like in-prompting for responses, asking about personal experiences, expectation request, pressing for ideas, revoicing, praising ideas, prompting for share out, describing how ideas are related from one group to another, validating ideas/phrase, pressing to share, and you finished with more directions for the next tasks."

The last video was Leslie's. The talk pattern was described as "I saw that directions were short. There were a lot of student-teacher-student-teacher (talk), and then small group discussions where students generated answers." The teachers noticed that students built upon each other's ideas while sharing their home experiences: "When one student talked about, "Oh, in Mexico,

we do this" and then the other student built upon, "Oh, yeah! Boiler, yeah!" When some students said something that was relevant to another student, that student jumped in, right away." What was being said by the teacher was described in detail. In addition to giving the direction, expectations, and management, two things were highlighted. One was providing an accommodation for a multilingual student, and the other was creating a safe space when the issue of being homeless was brought up:

> "Instruction for the task, redirecting students, expectation and management with the cell phone, giving accommodations for a language learner, like introducing that (EL) student to the other students, they didn't know him and he didn't have language to explain himself, she made that happen. prompting for student responses and validating the responses with "Cool", "I like that!", rephrasing and repeating, or expanding: "I've heard ... anyone else think of ….?" Set up the next task, clarify for students when they looked stuck, asking for student responses... set up a really clear expectation for the safe space, with like "You don't know the experiences of everyone, but I trust you" all of that putting them into place, and asking for students responses and expanding."

In addition, the graduate student and the researcher shared their noticing of "a lot of words of affirmation", "give positive treat", "emotion", and "laugh."

After viewing the videos: *"What are the things that you would like to see in your classroom?"* All three teachers noticed some discrepancy between the ideal images of classroom interactions that they collectively constructed before viewing and the actual images of classroom interactions in their teaching videos. The researchers initiated the conversation by inviting the teachers to set a goal. The researcher said, "What are the things that you would like to work on given the things that you saw? If you can set one goal for yourself, something that I would like to see in my class, what would that be given the things that you saw?" While positioning as an assistant who "can be your eyes and ears" and "just provide data for you," the researcher proposed, "[setting one goal] would be a good outcome from this viewing together. We can collectively work together toward the goal."

The teachers discussed four potential reasons why students did not engage in the conversations as much as they hoped to be. One potential reason was because of the lack of teachers' modeling of a good group collaboration. Adrina said, "I personally haven't modeled what's actually like...We [adults] have experiences before. But our 14, 15, 16 years old, haven't experienced what a true collaborative group looks like. I have not explicitly taught them." The second 'hypothesis' was that students did not see any connection with the tasks, so they didn't think it matters to them. The third potential reason was because students were "afraid to be wrong...they are not stepping out of their comfort zone and taking those risks." The researcher drew the teachers' attention to the critique on school sciences that often have 'the right answer' and epistemic injustice experienced by minoritized students. The last hypothesis offered by Anita was that students did not have social connections with other students in the classroom, therefore they were "nervous about being wrong...not feeling really confident about what I am going to say."

After reasoning about the possible reasons why students did not engage in the conversation as much as they hoped to be, the researcher asked the teacher to identify one thing that they would like to try and work to improve:

> The researcher: Which one, what would you like to do? How can I help you? What would you like to try tomorrow?

Leslie: I think being intentional in the relational work, if I am thinking of what would be helping to get notes [from you], 'Oh, I did that. Oh, that worked. I should do more of that.' I don't know if I am very intentional, anything.
The researcher: do you mean being more intentional in the relational work?
Leslie: Yes.
The researcher: Can you think of actions that you can actually try?
Leslie: I think, first, what I'd appreciate Anita, maybe I want to build off of that, literally building in time specific for it. This is just that time. Get to know your table. Making it a priority as far as timing in planning, I think.
The researcher: [wrote down on the poster] Making time and space.
Anita: I know this is always something that I am trying to say to my students. When you talk to someone, use their name. I know I started off really strongly at the start of the year, and I definitely, I stopped using that. I like to get back to, 'Okay, if you have a conversation with someone, acknowledge your name, [for example] 'Oh, Adriana, thank you for sharing!' something like that. Try to acknowledge you know who they are. Because, so many of them come up to me on the side and ask, '[whispering to the teacher] What is my lab partner's name?' Then I go, ' [whispering to the student] did you ask them?' [the student said] 'No.' [everyone laughing] You've been here all together, how do you not know their name? I really first the two weeks, I definitely, every time when you talk to someone, use their name. Try to get comfortable, using their name. I definitely taped off of that. But I want to build that back into mine. You know.
Leslie: It is so funny, I don't remember not knowing the name of people in class, personally. Also, if I think about it, White kids would not be offended if you did not know their name.
Anita: I felt bad. There was one class that I had in high school. I never met this girl. I cannot tell you who she was. Another Anita in one of my classes. And nobody knew who she was because I got all of her paperwork back. People will pass the stuff back, I got every single Anita's paper, and it was doubled. I go back and give it to the teacher, "This isn't me." She goes like, "It's not??" "No, you don't even know who this other girl is. Wow" [everyone laughing]
The researcher: From the other Anita's perspective, it is like totally invisible.
Anita: Right! I felt bad. I never went up and figured out who this girl was. Now I am trying to say [to my students], "You should know everybody's name! Use their names!"
Adriana: Or for the other student, I personally in my high school, I was like, 'Don't call me [head down and hide].' So I intentionally say, 'Oh, group 10. what did you think?' So I am not directly calling on a particular student because I don't want to put anybody in the hot seat. So I am a little bit more opposite.
Leslie: I am like, 'Somebody in Monica's group share.' So Monica can do it. I'd love Monica to do it. But somebody in Monida's group should share.
Adriana: I'm like, 'Oh my god, it is my name! I am horrible.' [laugh] Everyone takes our own experiences.

The three teachers expressed slightly different concerns, accordingly wanting to focus on and improve the aspect of practice that they found important to themselves. Adriana related the

discrepancy between the ideal image and the actual image of her teaching primarily to communicating the expectations clearly ("I have not explicitly taught them."). In contrast, Anita attended to social relations among students as the major source of challenges for students' deep engagement. It is notable that the teachers surfaced different views about 'calling on student names' in relation to their own personal experiences. Because the teachers were tasked to set one goal *collectively*, they collectively selected the goal of being more intentional about their relational work, with the shared understanding that this relational work substantially affected students' experiences. The teachers brainstormed a few concrete strategies together while generating the list on the big poster paper on the wall.

> The researcher: what I am hearing is you are all interested in working toward being intentional in the relational work? Is it what I am hearing?
> Teachers: Yes
> The researcher: So some of the strategies that I am hearing is really being planful in creating time and space, and also, being more individualized, also get them to know each other and call them each other with your name. So that's what I am hearing.
> Leslie: I don't want to fall into the trap though, this is the time and space for the relationship, and the rest is not.
> Teachers: Yeah. Agree.
> The researcher: How we are going to facilitate interactions through relational work is super important. Also, how we are going to relate ourselves to students as well. So do you want me to focus on, when I come back to your classroom, what kinds of intentional relational work that you are doing, either calling on student names, using emotional language, or affirming their contributions, validating or getting them to relate one another, something like that?
> Anita: I like that.
> The researcher: All right. I will focus on to what extent do the teachers intentional in facilitating relational work.

Discussion: Design Considerations for Supporting Teacher Learning for Social Transformation

In this participatory design research, we intentionally created professional learning contexts where high school chemistry teachers engaged in pedagogical imaginary (Gutierrez & Calabrese-Barton, 2015) to provide transformative learning for Latinx and multilingual students from socioeconomically disadvantaged communities. The three episodes illustrated the critical moments of teachers' making and sharing that were consequential on the students' experiences with chemistry in the classrooms. The close analyses of the emergent forms of learning in this partnership point to three design considerations for creating professional learning contexts toward transformative teaching and learning at schools: (a) the use of a conceptual tool (i.e., 'design principles'), (b) the power of "what if" discourses, and (c) creating a space for collective learning. These three considerations function as mediators of professional interactions toward transformative learning.

Design consideration #1: using conceptual tools ('design principles') to mediate professional interactions toward transformative teaching and learning

The first design consideration emerging from the analysis has to do with the use of a conceptual tool in partnership. In this project, the conceptual tool was the five design principles that communicated key lessons from the research on equitable science teaching and learning using practical language that is accessible to teachers, such as 'make it matter' (see the detail in Author and other, in preparation). The analysis showed that the skillful use of this conceptual tool mediated teachers' expansion of themselves toward transformative chemistry teaching and learning--being committed to making science matters to *their* students and supporting their students' sense-making. Specifically, this process of expanding the teachers' selves involves sharing the stories of each teacher's personal struggles and concerns about supporting students' learning and engagement based on their past experiences, and generating the meanings of design principles grounded in each teacher's teaching practice. It is important to note that the teachers framed their sharing of their rich stories based on *why* a particular design principle was "super important to me." While sharing their personal stories, values, and concerns, the teacher came to develop an ownership of the pedagogical goal communicated with the design principle that they chose while socially constructing its meanings along with their colleagues. Although the design principles were originally developed and introduced by the researcher, the teachers came to 'own' the design principles that they chose, which enabled them to be aware of their own commitments.

In addition, a skillful use of this conceptual tool helped the researchers and the teachers to develop and maintain 'subject-subject' relations (Bang & Vossoughi, 2016) during the co-designing activities while navigating power dynamics. Recall the second episode where the researcher could raise the question about the teacher-generated essential questions using the design principle selected by the teachers, without positioning herself as an authority. The fact that the design principles only stated goals, without describing specific actions, activities or tools, enabled both the teachers and the researcher to draw upon rich contextual knowledge about students and their communities to formulate locally responsive pedagogical actions. Both researchers and practitioners could leverage their knowledge, experiences, and concerns to design students' experiences toward the shared goal. There is a general consensus among several researchers that leveraging multiple forms of expertise is imperative to solve a complex educational problem, such as addressing inequity and injustice at schools (Bang & Vossoughi, 2016; Penuel, 2017). Historically, the education community has struggled to leverage the knowledge of both researchers and practitioners toward social changes in partnership settings. The analysis of this partnership project illustrates how the use of this conceptual tool can facilitate the process of leveraging both researchers' and practitioners' knowledge.

Lastly, the close analysis of the professional interactions mediated by design principles in this partnership project suggests that an intentional use of design principles facilitates teachers' sense-making conversation by drawing teachers' attention to 'why' of their practice. The presence of the design principles (e.g., making it matter) set up the teachers to constantly link their pedagogical actions ('what' to do) to goals ('why'). An example of this emerged in the second episode where the teachers and the researcher discussed, evaluated, and modified their unit essential question ('what' of practice) in light of the goal of making it matter ('why' of practice). Horn and Little (2010) note, "this movement between the particular and the general […] was a means of developing teaching knowledge that is deeply rooted in embodied accounts of classroom life, joining important concepts about teaching to particular practice." (p. 197).

Constant use of the design principles throughout the partnership project could set up and facilitate this constant movement from the "what" to the "why" about their practice, therefore could support the team's collective sense-making toward transformative ways of teaching and learning.

Design consideration #2: the power of "What if"

The second design consideration emerging from the analysis of learning in this partnership project is the powerful role of a discourse move, 'What if.' The analysis showed that a critical turning point in the process of teachers' making and sharing toward transformative teaching and learning was associated with collectively thinking about a pedagogical imaginary prompted by discourse moves like, "What if", "Just imagine…" "What might you expect to see in an ideal classroom?" The close analysis suggests that this discourse move mediated the shaping of this critical moment in two ways. First, this discourse move opened the space for collectively exploring new, alternative forms of learning while maintaining democratic subject-subject relations among the participants. Recall the second episode where the four teachers and the researcher interrogated and revised the unit essential question toward the goal of 'making it matter.' Each of the participants had different positionalities and power associated with their roles and status (e.g., a science education researcher in a research university, a student teacher who would be evaluated by the mentor teacher, a department chair and senior teacher). The discourse move of "What if" was observed a total of four times during a short exchange in this episode. Regardless of the status of the individuals, the idea shared with this "What if" discourse opened up a new possibility for the team to collaboratively explore and reason about important elements of their co-designed unit.

In addition, the "What if" like discourses enabled the participants safely to disrupt and challenge existing norms, practices, and ideas. An instance of this occurred in the third episode where the teachers and the researchers collectively generated the images of an ideal classroom where students develop the sense of mattering. The teachers expressed satisfaction about their own teaching practices before viewing their own teaching videos, despite the different affordances and learning opportunities for minoritized students noticed by the researcher. The discourse move of "just imagining what we might expect to see in an ideal classroom" invited the teachers to collectively construct the image of transformative learning, which was later juxtaposed with the actual images of learning observed in their own teaching videos. The existing practices of teaching and learning was safely challenged as the teachers themselves noticed the discrepancy between the ideal image of classroom interactions that they co-constructed and the actual image in their own teaching videos.

Design consideration #3: designing a space for collective learning

The third design consideration emerging from the analysis of learning in this partnership project is the power of learning together with the presence of multiple participants from diverse backgrounds. We recommend deliberately creating a space where the teachers share, relate, and make *collective* pedagogical decisions toward transformative teaching and learning, instead of staying at individual choices. Throughout this partnership project, the teachers and the researchers shared personal stories, concerns, and values while providing abundant opportunities to make and share their individual choices. Notably, the teachers were eventually tasked to make pedagogical decisions *collectively* as a team, instead of staying with individual goals and choices. The analysis suggested that this act of making a collective decision opened up new

possibilities for the teachers to explore new pedagogical horizons that they would not try otherwise. Recall Adrina who reasoned about her students' lack of engagement in relation to insufficient communication about the expectations after watching the teaching videos. Adriana expressed her dilemma between facilitating the conversation and managing the classroom, reflecting her concern of maintaining an orderly classroom. She said she wanted to work on the practice of more explicitly modeling the behaviors that she wanted to see from her students. In contrast, the other teacher, Anita, noted students' struggles in socially connecting themselves with other students in the classroom. Through this collective reasoning and decision-making, the team decided to focus on "being intentional in their relational work" to create a safe and welcoming environment. This collective decision opened up a new opportunity for Adriana to explore the new terrain of teaching practices that she might not prioritize otherwise.

The prior research on teacher learning for equity and justice tended to focus on increasing individual teachers' capacity (i.e., knowledge, belief, orientation, attentiveness, etc.), despite the grounding in sociocultural theories of learning. The analysis of teachers' making and sharing in this partnership project suggests that deliberately designing professional learning for a collective, with the consideration of multiple people who bring diverse perspectives, their own relations with people and the discipline, are critical to facilitate teachers' movement toward social transformation. The teachers were key actors of the activity system who co-constructed their learning experiences through their sharing, relations, and interactions. It would be almost impossible to tease out one individual teacher's change without considering her relations and interactions with other teachers in this particular setting. Across the three episodes, the teachers and the researcher came to hear themselves as well as others while sharing why a particular design principle was so important to them, or why students might not engage as much as they hope to be. These multiple concerns, stories, and alternative modes of learning informed the teachers' collective decisions, which pushed them to go beyond what they could do individually.

Conclusion

In this project, we created a professional learning context in which high school chemistry teachers engaged in a 'pedagogical imaginary' (Gutiérrez & Calabese Barton, 2015) by leveraging their teaching experiences, knowledge about students and communities, values, and concerns to create powerful learning contexts for Latinx and multilingual students from immigrant, low-income families. Drawing upon the perspective of learning as making and sharing of the world interwoven with making and sharing of selves (Warren et al, 2020), we analyzed teachers' participations and discourses to examine teachers' making and sharing that were equitably consequential. The findings illustrated three critical moments of teachers' makings and sharing where: (a) the teachers collectively developed shared pedagogical goals toward transformative learning while formulating agency, (b) the teachers and the researchers came to design a creative stoichiometry unit where students use chemistry to make their community better, and (c) the teachers came to be committed to being 'intentional' in their relational work to create a welcoming and safe learning environment using concrete pedagogical strategies. Based on the analysis, we made three recommendations for designing professional learning contexts toward transforming teaching and learning at schools. First, we recommend using a conceptual tool that translates an abstract commitment or ideology, such as 'promoting equity and justice' into concrete pedagogical goals that the teachers can relate to and work on throughout the partnership. Through the co-generating the meanings of the pedagogical goals between teachers and researchers, the conceptual tools can help the team to engage in principled

and adaptive pedagogical decisions toward transformative learning. Second, we recommend strategically facilitating teachers' collective imagination using discourse moves, such as "what if." A facilitator or a coach is a key actor who plays an important role in shaping a professional learning environment. Future research about the facilitation would be fruitful and informative to design professional learning contexts. Lastly, we recommend attending to the importance of collective pedagogical reasoning and decision making in addition to giving opportunities for teachers to make their own individual choices. Making a choice is associated with formulating a sense of ownership and agency. Learning as a collective can open the new horizons for the teachers to move towards transformative teaching and learning.

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Table 1: eight articles that studied mathematics or science teacher learning for equity and justice in the secondary education

Authors	Assumption about promoting equity and justice	Key construct	Data sources	Observable changes
Bartell (2013)	Teaching for social justice is not a matter of method but a process requiring teachers to adapt to the particular context of which they and their students are part (Cochran-Smith, 1999). Learning to teach for social justice will not "happen" in one graduate course; it is a "lifelong undertaking" and complex process requiring effort, perseverance, and reflection (Darling-Hammond, 2002, p. 201). It also requires teachers to see it as such (Gutierrez, 2009)	*Darling-Hammond's theoretical model of equity pedagogy*: Self, Society, Students, and Schools. Teachers learning to teach for social need: (1) an understanding of themselves, both personally and in relation to others (Self); (2) the understanding how power structures interact with teachers' understanding of teaching and learning; (3) to get to know their students well (Students); and (4) to consider their evolving understanding of self, students and the social contexts that affect learning and teaching so as to develop and enact classroom practices that support their students (School)	Graduate course and debriefing sessions, written teachers reflections, lesson plan artifacts, teachers' final course papers reflecting on the lesson study process, and teacher interviews	Mathematics teachers' negotiation of the two **goals** of (a) mathematics and (b) social justice in their practice. Looking at how teachers' **conversations** about teaching mathematics for social justice changed over time by examining the negotiations in practice
Brenner et al. (2016)	Teacher learning as a process of enculturation into a community of practice. Teacher as researcher (knower and agent	Teacher research as a way to promote equity and educational equity	Teacher's research documents, classroom observations,	How teacher' research (initial wonderings, formal research, and next research steps) aligned

	for educational and social change) to identify areas for improvement, if not transformation, and address them through the practice of inquiry, action, reflection, and learning. Teachers begin with "wondering worth pursuing" and then work to transform such wonderings into researchable questions		professional development meetings, and teacher interviews	with three strands of equity; and how participation in teacher research reinforced, challenged, and/or **transformed teachers' views and reported practices**
Brown & Crippen (2017)	The knowledge of a culturally responsive teacher operates at both micro- and macro-levels. Micro-level culturally responsive knowledge focuses on the teacher-student level, irrespective of larger social and institutional forces. Such intimate knowledge permits culturally responsive teachers to determine specific student learning needs and make necessary adjustments to instruction. A macro-level understanding of the political and historical underpinnings of schooling is also necessary to foster critical consciousness in students of color, an important element of culturally responsive instruction.	Culturally responsive pedagogy (CRP) is described as assisting students in "the development of a "relevant black personality" that allows African American students to choose academic excellence yet still identify with African and African American culture (Ladson-Billings, 1994). It aims to strengthen the academic performance of students of color by using their cultural knowledge, prior experiences, frames of reference, and performance styles (Gay, 2010)	Classroom observations, group interviews, and several artifacts	Science **teachers' knowledge and practices** around culturally responsive science teaching

Felton-Koestler (2019)	Gutiérrez's way of framing equity: play the game and change the game. Learning to play the game emphasizes providing students with greater access to what Gutstein refers to as "classical" mathematics—the mathematics that is typically taught in school. Learning to change the game involves engaging learners in using mathematics to analyze social and political issues, especially injustice.	Valsiner's zone theory (1997) for understanding teacher change. The zone of free movement (ZFM) is the socially constructed set of all actions that are acceptable in a given setting	A teacher's written reflection about readings on Teaching and Learning Mathematics for Social Justice, and a semi-structured interview	Shifts in a teacher's teaching **beliefs** and **practices**. The teacher's beliefs and views about the nature of mathematics, students' abilities, and how children learn mathematics.
Louie (2017)	Framing can be a fully conscious, deliberate activity, as when people work to unsettle the dominant culture by asserting alternative frames. Learning for equity and social justice involves to alter the culture of exclusion in mathematics classrooms by actively "reframing" mathematics teaching and learning in ways that expand students' opportunities to learn	Culture and activity to understand reproduction and alteration (Durkheim, 2013): Culture and activity are not unidirectional; moment-to-moment activity is simultaneously born from and gives birth to culture. Cultural ways of noticing, interpreting, and doing shape the possibilities for thought and action that are available at a given time and place, but through their interactions people alter as well as reproduce cultures.	Class observations	How teachers **framed** the nature of mathematical activity (i.e., what it means to do mathematics) and the nature of mathematical ability. In place of teachers' meanings, the author focused on their instructional practices alignment of those practices with particular frames.
Planas & Civil	Learning to teach for social	*Bauman's complexity model*:	Group discussion	Development of

(2009)	justice is related to the process of empowerment. People with less control over the legitimate cultural and social resources in a context need to develop a process of ‘‘empowerment’’ that will enable them to actively participate in the social construction of this context. Empowerment is a process of increasing personal and interpersonal power so that individuals can take action to improve their life situation (Gutiérrez 1995). We believe that those individuals with a feeling of having power are more likely to contribute to the actions for social change.	The complexity model understands freedom as a responsibility oriented toward an improvement of the living conditions of the different groups in order for all of them to gain more control over resources. The process of empowerment cannot begin until a person accepts responsibility. Any process of ‘individual’ empowerment is necessarily a collective process based on the improvement of the community (Gustein, 2006)	sessions, and mathematics class observations	teachers’ empowerment processes. The authors wanted teacher participants to assume that one of their main **goals** when teaching mathematics is to increase their students’ actual power; i.e., to make student achieve mathematical learning that prepares them not only for future classes but also for personal and social life experiences
Rosebery et al. (2016)	Equity and diversity are interrelated in the practice of teaching. Teacher learning for justice involves “a pedagogical imaginary” (Gutierrez & Calabrese-Barton, 2015), which is based on the assumption “equity and diversity are inextricably linked in the practice of teaching. Learning to teach effectively and justly	*Interpretive power*: teachers’ attention to students’ diverse sense-making repertoires as intellectually generative in science teaching and learning	Teachers’ responses to a deliberately designed tasks	Teachers’ increasing **attunement** to the forms and functions of (a) students’ wide-ranging sense-making repertoires as generative intellectual resources in science teaching and learning, and (b) expansive pedagogical practices that encourage, make

	entails "a pedagogical imaginary" (Gutiérrez & Calabrese Barton, 2015) in which it is assumed that students make sense of the world in diverse ways and that teachers are oriented toward students' sense-making in a relationship of "actively responsive understanding" (Bakhtim, 1986)"			visible, and intentionally build on students' ideas, experiences, questions, and perspectives on scientific phenomena (p. 1572)
Wager & Foote (2013)	Equitable mathematics pedagogy (Wager, 2008), Attention to the sociocultural factors that affect the teaching and learning of mathematics. Teachers (a) reflected on theories and understandings gained from text and observations, (b) incorporated these perspectives into views of equitable mathematics teaching and learning, and (c) determined where action must be taken to achieve equitable mathematics pedagogy. Teachers enter a space where they could confirm, deny, or expand their identities as standards-based mathematics	Praxis. By incorporating Freire's view of action for transformation, we more specifically define Aristotle's "goal of realizing something worthwhile" as working to achieve equity in mathematics learning through reflection and action. Praxis is not the end itself but action that leads to the goal, the process of reflecting on and putting theoretical knowledge into practice that transforms. Figured worlds. Holland and colleagues describe figured worlds as "sociohistorical, contrived interpretations or	Teachers' autobiographies and semi-structured reflections	**Teachers' identities** within three figured worlds: (1) standards-based mathematics; (2) multicultural education; and (3) equitable mathematics pedagogy

	teachers while doing the same for their identities as culturally relevant teachers.	imaginations that mediate behavior and so, from the perspective of heuristic development, inform participants' outlooks" (p. 52). We use this definition to consider the way the teachers constructed the figured worlds of standards-based mathematics, multicultural education, and equitable mathematics pedagogy and how teachers' developing identities within those figured worlds.		