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Discontinuities that arise when designing for educational improvement at state scale

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This paper explores the tensions—or discontinuities—that arise when designing for educational improvement at scale through research-practice partnerships (RPPs). Focusing on a statewide mathematics education initiative, the authors examine the complexities of coordinating work across diverse communities of practice and analyze how identity, power, and meaning-making impact collaborative problem definition. Drawing on Wenger's dualities of participation-reification and identification-negotiation, the study highlights three recurring discontinuities: navigating the ambiguity of the design process, designing for diverse system stakeholders, and negotiating shared vocabulary. Through qualitative analysis of team reflections, activities, and artifacts, the paper offers practical strategies—such as participation structures and system mapping—to support productive boundary encounters and restore continuity. These insights advance both theory and practice for those undertaking equity-oriented design at large scale.

KEYWORDS

design based research, discontinuities, community of practice, large scale, research practice partnership

Introduction

Researchers and practitioners commonly agree that there is a wide gap between their professional worlds, with few effective bridge-building solutions. One approach to narrowing this gap has been for researchers to become better at *translating* their results to practitioners (Penuel et al., 2015). However, this unidirectional approach perpetuates an elitist view that researchers know what practitioners need in order to fix their own challenges and positions practitioners' knowledge as secondary to researchers'. Additionally, when practitioners are not involved in research that influences their work, the outcome is typically disappointing in that findings are not taken up in practice (Fullan, 2008). An alternative solution is to form reciprocal partnerships such as those in research-practice partnerships (Coburn et al., 2013), participatory design research (Bang and Vossoughi, 2016), and teacher design teams (Handelzalts et al., 2019) in which researchers and practitioners engage in collaborative problem solving. Critical and feminist scholars like Lather (1991) argue that research methods fostering *reciprocity* between researchers and practitioners (i.e., the mutual give and take within social interactions) can lead to research outcomes that are more accurate and implementable. Not only do reciprocal research methods have the potential to empower those who are traditionally *researched* but they also lead to solutions for problems that are closer to the work of practitioners.

Research-practice partnerships (RPP) have become more common in educational research, involving long-term collaborations working toward educational improvements or

equitable transformation through engaging in research activities (Farrell et al., 2021). RPPs have the potential to address power imbalances, narrow the gap between research and practice and build organizational capacity. Scholars who write about RPPs overwhelmingly draw on conceptual tools from situated theories of learning such as *communities of practice* (Wenger, 1998) and *Cultural Historical Activity Theory (CHAT)* (Engeström et al., 1995) to understand the interactions, and therefore learning, that take place within newly formed spaces of collaboration. For example, Penuel et al. (2015) conceptualize RPPs as *joint work* involving *mutual engagement* among members from distinct communities. They argue that the joint work of partnerships requires participants to cross the boundaries between their social worlds into a shared boundary space of the partnership where a variety of practices and artifacts can support meaning making. Prolonged engagement with particular activities at the boundary of two or more sociocultural contexts can be enabled and constrained by differences among participants' actions, intentions, and meanings, but re-establishing ongoing action can result in knowledge production (Akkerman and Bakker, 2011).

Despite the potential of RPPs to serve as cross-cultural boundary spaces of learning, there are several potential challenges that can result from engaging participants from multiple professional and cultural backgrounds (e.g., teachers, researchers, superintendents, state education agents). Instances where participants draw on culturally specific practices from outside the boundary space that conflict with others can cause disruptions in progress, also referred to as *discontinuities*. Discontinuities are tension-filled encounters at the boundary that require participants to change their perspective, continue in tension or end the relationship altogether. Changing perspective so that engagement continues productively, i.e., re-establishing continuity in action and interaction, can lead to renewed commitment and purpose (Bronkhorst and Akkerman, 2016). *Boundary practices* and *objects*, whether brought in from the outside or newly formed within the boundary space, can be important tools to navigate discontinuities and support new learning. In this way, differences can be worthwhile for meaning making, not obstacles to avoid (Akkerman and Bakker, 2011). Analyzing boundary encounters that bring about discontinuities, particularly when continuity is re-established, can help researchers understand the ways in which participants draw on their participation in cultural practices from outside communities to negotiate the differences within the RPP and potentially form new meanings.

In this article, we use the ongoing work of the North Carolina Collaborative for Mathematics Learning [NC2ML], referred to as Mathematics Collaborative from heretofore, to identify discontinuities that arise when bringing together individuals from multiple educational communities to engage in joint work around choosing a shared statewide problem. The Mathematics Collaborative is a large scale research practice partnership of researchers from 13 [State North Carolina] universities, mathematics educators from the state education agency and over 300 state, district, and school-based leaders and mathematics teachers. It is large scale in the sense that it involves researchers and practitioners from different types of school districts (rural, urban, suburban), participants representing a variety of roles (state education agency, researchers, K-12 educators), and covers a large geographical area (state of NC) comprised of dozens of smaller educational systems (115 school districts). The partnership formed in 2016 when the state began adopting new K-12 mathematics standards and has taken a design-based implementation research approach (Fishman et al., 2013) to collaboratively develop implementation resources, create professional learning materials, and grow a state-wide infrastructure that supports mathematics teaching and learning through networking and advocacy. During this time, project leaders noticed that there was little coherence in the way the new standards were being implemented across the state, with only a few pockets doing so in ways that are consistent with National Council of Teachers of Mathematics (2014) vision of high quality, equitable mathematics instructional practices. Thus, in 2021, the Mathematics Collaborative shifted from co-designing for state-wide standards implementation to co-designing to promote a shared vision of high quality, equitable mathematics instruction (VHQEMI) due to a perceived lack of common instructional vision. To this end, the partnership formed three Co-design Teams, one at each of the three grade bands (K-5, 6–8, 9–12). Each of these smaller teams began the process of identifying a state-wide problem of practice that, from their perspective, has resulted from disparate instructional visions across the state educational system.

In 2016, the emerging statewide problem of practice for our RPP was defined for us by a policy change (the introduction of revised state mathematics standards). However, this new focus on co-designing for a state-wide VHQEMI offered us a unique opportunity to exercise more autonomy over determining a problem of practice for which disparate instructional visions is a root cause yet presented new challenges that are rarely discussed in research. RPPs begin, in part, with researchers and practitioners identifying shared goals for improvement and often a shared problem of practice (e.g., Cobb et al., 2020; Miller and Pasley, 2012; Munter et al., 2020; Van den Akker and Nieveen, 2021). A shared problem of practice (PoP) is a practical challenge that serves the needs of both researchers and practitioners and often involves multiple stakeholders working reciprocally to generate both theoretical and practical outcomes. According to much of the literature, RPPs are typically formed at the request of one of the partners who has a general problem or research interest that may serve as the basis for a more formal problem of practice. For example, in an RPP between a district and researchers in Washington, a superintendent approached researchers to conduct an audit of their newly adopted science curriculum (Penuel et al., 2013). As a result of this audit, researchers found that the materials had not been implemented in a manner that met the needs of their learners, and this became their shared problem of practice. In this case, as in many others, the PoP was identified around an issue that was of central concern of one of the partners. It is rarer to convene a group of diverse stakeholders with no particular pre-identified problem and define one together, especially at a state-wide scale. Such an approach presents an opportunity to empower partners to identify their own problems (cf. Munter et al., 2020) for which disparate system-wide vision may be a root cause, as well as understand the difficulties that arise when choosing a problem that addresses the needs of an entire state's educational stakeholders.

A second challenge rarely addressed in RPP literature relates to the number and diversity of the communities represented in the partnership. The Mathematics Collaborative is a statewide constellation including members that represent the most diverse set of communities of practice (CoP) we have found in the literature to date: 115 school districts, each of which can be considered its own CoP and individuals from six unique role specific CoPs (teachers, school or district-based

coaches, district leaders, administrators, state level educators, and researchers). The analysis we offer in this article illuminates the unique set of challenges that can arise as partners from multiple, interconnected education communities come together to identify problems that will potentially resonate across an entire state. We also examine what designed activities and artifacts supported this joint work as well as those that emerged during negotiations to enable the work to move forward meaningfully. In doing so, we hope to provide others taking on such statewide educational challenges with strategies and tools to facilitate their work. While we acknowledge that VHQEMI frames co-designers' work in identifying a problem of practice, this article forefronts the discontinuities that arise when RPPs co-design at large scale, not how vision mediates co-design work (a paper in and of itself).

While the context of our work is mathematics education, research practice partnerships have been developed in other content areas such as literacy (Campano et al., 2016; Snow and Lawrence, 2011), multlingual education (Umansky and Reardon, 2014), and science education (Penuel, 2017). Coburn and Penuel (2016), in fact, call for more research on tools and strategies for facilitating equitable RPPs. Our findings can be beneficial for both mathematics education RPPs working at state scale as well as others outside of mathematics who aim to create large scale RPPs.

Theoretical constructs

Wenger (1998) introduced the notion of communities of practice to describe organizations of individuals who engage in collective meaning making around a set of shared goals. Not every collection of individuals is a community of practice (CoP) but those that are share three characteristics: (1) there is a shared domain of interest (e.g., improving mathematics education within the state), (2) members are mutually engaged in joint work (e.g., defining a state-wide educational problem of practice), and (3) engagement leads to a set of practices and artifacts that define the community (e.g., empathizing with members with different roles than them). From this point of view, learning is not a matter of acquiring new knowledge through manipulation of symbols but rather transforming one's participation in a community of practice (Barab and Duffy, 2000). In an attempt to understand how individuals from two or more communities learn from one another, researchers examine emerging and ongoing boundary encounters which describe sociocultural trading zones where meanings, practices and objects are brokered among participants (Chen et al., 2010; Kislov, 2014; Wenger, 1998; Wenger et al., 2002). Within any CoP, there are several inescapable *dualities* that describe the relationship between individuals and the collective and are fundamental mechanisms of learning. A duality is a single conceptual unit that is formed by "two inseparable and mutually constitutive elements whose inherent tensions and complementarity give the concept richness and dynamism" (Wenger, 1998, p. 66). Dualities refer to the intersecting yet differing activities and needs that drive the engagement in a community (Engeström, 1987) and can interrupt (discontinuity) collective and individual learning (Akkerman and Bakker, 2011; Engeström, 1993). In particular, the dualities *participation-reification* and *identity-negotiation* form the basis for collective and individual learning, respectively and are the two dualities that we discuss in greater detail as they help explain the emergence of the discontinuities in our work.

Dualities as mechanisms for collective and individual learning

The first of such dualities, *participation-reification*, refers to the idea that individuals create meaning through active participation in a community of practice. At the same time, these acts of participation, through mutual engagement with community others, can lead to reifications (concretizations) of those meanings into community objects, processes and practices. Participation and reification require each other; it takes participation in joint enterprise to create reifications and participation relies on former reified actions and objects. It is through participation in a boundary encounter that *collective learning* is negotiated and reified into community objects and practices. A sign that a community is learning is that (a) its mutual engagement (including relationships among members) shifts form, (b) its enterprise is fine-tuned through negotiations and (c) its repertoires, discourses, and styles evolve (Wenger, 1998).

A second, related duality involves the extent to which *individuals* learn (although from a social perspective) through participation in the community. Wenger argue that it is through engaging in a layering of participation and reification events that individuals *negotiate* who they are, their very *identity* in this boundary space, as they develop relationships with others (Wenger, 1998). Attending to the *identification-negotiation* duality can lead to understanding how individuals learn within a boundary encounter through negotiations within participation and reification events. Discontinuities can arise when there is an identity crisis (e.g., who am I to do this state-wide work?). Identifying these moments of disruption and ways to support identities related to this boundary space can lead to *individual learning*. Attention to the tensions arising related to the identification-negotiation duality can also reveal how power is distributed within a CoP and the ways in which imbalances can be restored.

Together, these dualities serve as primary mechanisms of collective and individual learning when they provoke discontinuities, i.e., interruptions in practice resulting from sociocultural differences that arise in boundary encounters as individuals from two or more communities negotiate meaning, actions, and resolutions (Akkerman and Bakker, 2011). For example, the adoption of the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010) caused a major discontinuity for many school communities, districts and families. Veteran educators and others struggled to *identify* with new instructional practices that, to them, were unorthodox and grounded in research generated, in their minds, by individuals outside of the local context of schools and communities. In terms of mathematics, the Common Core State Standards challenged traditional notions of what it means to know mathematics, providing an opportunity for individuals to make meaning of these standards in ways that were consistent or not with their own mathematical *identities*. New tools and processes were introduced and generated to support *participation* in these new practices. Attending explicitly to *participation-reification* and *identification-negotiation* dualities can explain why certain discontinuities arise and how to restore continuity.

Constellations of interconnected practices

Modern day globalization capabilities have required researchers to expand CoP constructs in order to consider organizations with participants from more than two communities. The Mathematics Collaborative is a statewide research practice partnership whose participants engage in boundary encounters with individuals representing six or more different but connected educational communities of practice. Such a vast number of communities represented within any one Mathematics Collaborative boundary encounter suggests that the partnership represents not one CoP, but rather a *constellation of interconnected practices* (Chen et al., 2010; Kislov, 2014; Wenger, 1998). Constellations of interconnected practices refers to complex social configurations in which differing yet connected practices become explicit at the boundaries between participants. Boundaries, in essence, become trading zones in which participants bring local practices to the global space, and through negotiations create meaning, artifacts, and new boundary practices that represent reifications of meaning. When those meanings, activities, and artifacts are taken back and used within local communities, they can become *boundary objects* that are used for collaboration in other communities (Star and Griesemer, 1989). Importantly, boundaries represent the "sociocultural differences between practices leading to discontinuities in action or interaction" (Akkerman and Bakker, 2011, p. 133) and are sources for learning, not events to avoid. Discontinuities in boundary encounters can be generative events, leading to new learning, practices and artifacts or they can remain unresolved.

In this article, we explore the ways in which the dualities inherent in working within our constellation of interconnected practices surfaced discontinuities and the means by which members attempted to re-establish continuity. We analyze data from one particular boundary encounter, a three-day summer retreat. During summer 2022, over 80 individuals representing multiple mathematics education communities of practice convened over 3 days to identify a statewide problem of practice at each grade band (K-5, 6–8, and 9–12) and begin the process of co-designing for it. As project team leaders, we designed and adapted several activities and artifacts to facilitate this goal, with the anticipation that they might be useful or that new objects/activities might emerge within interactions. A central tension for leaders within an RPP is the extent to which tools and activities should be introduced at the boundary to facilitate participants' interactions. On the one hand, imposition of tools and activities can reinforce power dynamics among researchers and practitioners. On the other hand, providing no guidance may end the partnership before it even starts. With this tension in mind, we were interested to learn what discontinuities surfaced as co-designers chose their problem of practice and what activities and artifacts were taken up by co-designers' working through these discontinuities. Would there be common tensions across all three grade bands and what practices and objects supported the re-establishment of continuity, if at all?

> *RQ1*: In what situations and under what conditions did common discontinuities in learning across the three grade bands occur?
>
> *RQ2*: In what ways did commonly designed or emerging boundary objects and interactions support the re-establishment of continuity?

In answering these research questions, we would be able to inform other statewide design-based constellations of interconnected practices about the potential supports that can guide partners through their differences. To answer these questions, we begin by describing the Mathematics Collaborative research practice partnership. We then present the research methods, share three main findings, and discuss implications of this work.

The research practice partnership: the North Carolina collaborative for mathematics learning

As noted prior, the Mathematics Collaborative is a partnership of researchers from 13 North Carolina universities, mathematics leaders in the state education agency, and over 300 collaborating district leaders, instructional coaches, and mathematics teachers. The partnership formed in 2016 and has taken a design-based implementation research approach (Fishman et al., 2013) since then to collaboratively develop implementation resources, create professional learning materials, and grow a statewide network to support teaching and learning through networking and advocacy. The Collaborative has organized and refined the RPP using a set of guiding principles that connect our theoretical perspective on learning to the learning environment we aimed to support (Wilson et al., 2017). During the first 5 years of the Mathematics Collaborative, we noticed that high quality, equitable mathematics instruction, as described in *Principles to Action* (National Council of Teachers of Mathematics, 2014), was only enacted in small pockets around the state (see Wilson et al., 2024). Thus, in 2021, project leaders secured funding to continue collaboration, this time with a focus on exploring the conjecture that developing a *shared statewide* vision of high quality, equitable mathematics instruction (VHQEMI) is foundational to successful implementations of STEM education innovations at state scale (a conjecture supported by Kaufman et al., 2016). The four-year *Visions* project began by convening three grade band Co-design Teams, each consisting of approximately 20 mathematics educators from across the state. Each Co-design Team would identify a problem of practice that would resonate with mathematics educators within their grade band statewide, and co-design and/or adapt resources and infrastructures that could help solve the problem. The main goal of this article is to understand what discontinuities arise as members of a large constellation of interconnected practices identifies a problem of practice and is less about the way that members' visions mediate their co-design. Consequently, we do not provide a rich review of research on teachers' visions of high quality, equitable mathematics instruction.

Organization of the Visions Project

Anticipating the variety of communities that would be represented within each Co-design Team, the Project Team asked individuals from those communities to serve on a Steering Committee, whose responsibility it would be to draw on their unique perspectives to guide the work of each Co-design Team. The Steering Committee members would lead all meetings, decide which artifacts and activities would be used and make in-the-moment revisions when they sensed tensions. Convening Steering Committees, comprised of researchers

and practitioners, was an intentional design choice by project leaders who were researchers. We were aware of the power imbalance potentially exacerbated by having RPP meetings led by only researchers and hoped the Steering Committee would enable more equitable participation from co-deisgners. Notably, only two classroom teachers were able to serve on the Steering Committee (Middle Grades) due to the lack of flexibility of their time and the heavy responsibility beyond classroom instruction. Given this lack of representation, K-12 Steering Committee members made every possible effort to empathize with and support classroom teachers. An organizational sketch of the structure of the Visions Project can be seen in Figure 1. The *Project Team* members were higher education researchers and doctoral students whose primary responsibilities included all research activities, supporting the Steering Committee, and participating in co-design efforts, lending both theoretical and practical knowledge. *Steering Committee* members were charged with reviewing applications for Co-design Team membership, ensuring that *Co-design Teams* members shared vision of high quality and equitable mathematics instruction, and planning for and implementing all co-design meetings. Since we were choosing a problem of practice for an entire state of mathematics educators, the Steering Committee was charged with choosing co-designers that represented the state's diversity in several ways: (1) geographical region of the state, (2) district type, (3) members from minoritized communities, and (4) educational role (e.g., classroom teacher, principal, etc.). For their part, co-designers were expected to collaboratively identify a statewide problem of practice, design or adapt existing resources that would support educators to solve this problem and collect/analyze data on resource implementation to monitor progress toward solving their challenge. The Project Team recognized that such a commitment to diversity of role- and community-representation might surface discontinuities related to "fields of identification and negotiability" (Wenger, 1998, p. 235) and designed potential participation structures to attend to this duality. The findings we report in a later section indeed indicate that such structures were needed and important for equitable participation in the co-design process.

Once all co-designers were selected in Spring 2022, each Steering Committee hosted meetings in a virtual setting to engage grade band teams in a book study of Francis Su's *Mathematics for Human Flourishing* (Su, 2020), and to prepare for a three-day, face-to-face retreat in the summer. During this same spring semester, the Project Team held listening sessions across the eight state regions at which local teachers, coaches, and district-level leaders came together to describe their vision of high quality, equitable mathematics instruction, along with barriers that exist in their communities that prevent progress toward achieving that vision. The data from these listening sessions were gathered with the intention of identifying common struggles across districts that could inform Co-design Teams as they identify a statewide problem of practice. The Steering

K-5 (24 members)	6-8 (26 members)	9-12 (24 members)
Project Leaders: 2 university researchers, 1 doctoral student	**Project Leaders:** 2 university researchers, 1 doctoral student	**Project Leaders:** 2 university researchers, 1 doctoral student
Steering Committee Members 2 district leaders 1 university researcher	**Steering Committee Members** 1 school principal 1 university researcher 2 classroom teachers	**Steering Committee Members** 3 district leaders
Co-design Team *2 classroom teachers* *5 district leaders* *4 district coaches* *3 school coaches* *4 higher education researchers* ***District Type:*** *44% urban, 22% suburban, 33% rural* *Region Diversity: Evenly spread* *4 educators from minoritized populations*	**Co-design Team** *3 classroom teachers* *5 district leaders* *3 district coaches* *3 school coaches* *3 district math/sci coordinator/specialists* *2 higher education researchers* ***District Type:*** *30% urban, 25% suburban, 40% rural, 5% private* *Region Diversity: Missing 3 regions* *3 educators from minoritized populations*	**Co-design Team** *6 classroom teachers* *5 district leaders* *1 district coaches* *1 school coaches* *4 higher education researchers* *1 district testing coordinator* ***District Type:*** *50% urban, 20% suburban, 30% rural* *Region Diversity: 4 from two regions, rest equally distributed* *3 educators from minoritized populations*

FIGURE 1
Organizational structure of the Visions Project.

Committee members analyzed the data from the listening sessions and crafted two to three potential problems of practice statements for the Co-design Teams to consider in the summer. Meanwhile, the Project Team was designing a structure and agenda for the three-day summer work, consisting of a common opening session, individual grade band co-designing sessions and multiple cross grade band share outs. Next, we describe some of the activities and artifacts that we designed/adapted for co-design facilitation.

Designing to identify a statewide problem of practice

The Project Team created a three-day agenda that we hoped would facilitate the work, knowing that many of our artifacts and activities may not be taken up by grade band groups. These artifacts and activities were designed to provide a common design process across grade bands, facilitate working across role groups, and determine a problem of practice at each grade band that would resonate with a variety of mathematics educators across the state. Although there were multiple artifacts and activities that facilitated co-design, we only describe the ones that are relevant to this article and that were used by all three Steering Committees.

Common artifacts

The Steering Committees used *Mathematics for Human Flourishing* (Su, 2020) and virtual meetings to begin building a collaborative design environment, discuss the importance of shared vision of HQEMI, and better define for co-designers what is meant by a problem of practice. Identifying a problem of practice at *state scale* was new to all retreat participants, including the Project Team. When thinking about how our partners design professional development and classroom instruction, we realized that the problem to be addressed by their PD or lessons is typically defined for them and is often situated within a relatively local context. Considering the novelty of beginning the work before a PoP has been identified, the Project Team sought to design tools that would bring structure and guidance to the process of defining a problem and eventually developing resources to address it. On day one of the summer retreat, all members were introduced to a set of Commitments and Design Principles (Figure 2) and Characteristics of Problems of Practice (Figure 3) that were meant to initiate negotiations around a set of norms for co-designing for a state education system.

Co-designers discussed, edited, and ultimately agreed upon these principles before groups began working together within their grade bands. These commitments and principles were posted in each workspace and served as an anchor for groups as they moved forward in determining their PoP. The commitments and design principle statements were a constant reminder that the intention of the work was to serve students and teachers across all of NC, so that co-designers were challenged to think beyond their local context when considering PoPs and potential solutions.

The Project Team anticipated that not only would identifying a problem of practice likely be new to most participants, but that the systemic nature of the task (as reflected in Figure 3) would be as well. Classroom teachers and instructional leaders are most often tasked with solving practical problems in relatively short amounts of time, needing to take into consideration only the needs of their individual school or schools in their district. Therefore, artifacts and activities would be needed to attend to tensions related to being asked to see yourself within a larger system and think beyond your own context.

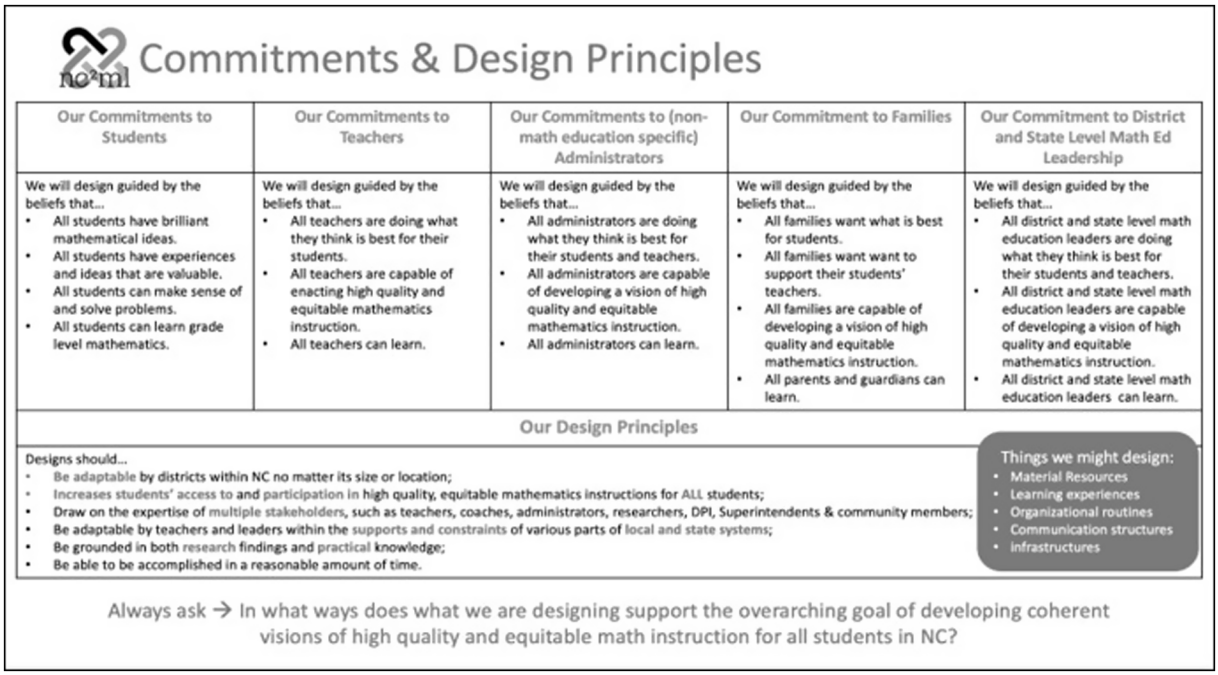

FIGURE 2
Commitments and design principles.

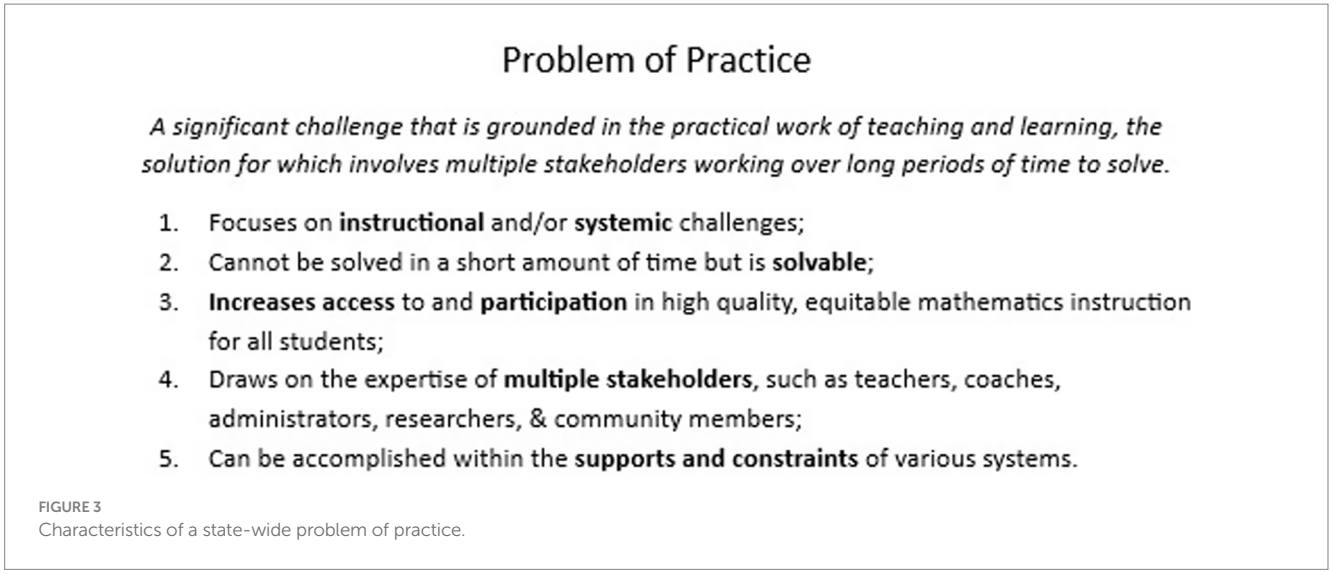

FIGURE 3
Characteristics of a state-wide problem of practice.

Another artifact introduced by the Project Team was an image of the design process (d.school, 2018) showing the six stages of design within hexagonal regions (Figure 4). This artifact was meant to situate current work of the design teams within the larger iterative process of design and was posted in each Co-design Team room. This artifact/process was designer-introduced, yet as we will see in the findings section, participants' use of this tool varied. We anticipated that a large portion of the summer work would be devoted to the *empathize* (attending to the voices of the people for whom you are designing), *define* (identifying/defining a PoP) and *ideate* (brainstorming solutions to the PoP) stages of the design process with prototyping, testing and assessing to occur in the fall.

Finally, all members had access to all artifacts, notes, and co-design materials. Each member was designated their own, online *Designer's Notebook* accessible by Steering Committee members and were periodically asked to keep reflections on the design process and other topics there. We hoped that the Designer's Notebooks might be places for Steering Committee members to look for feedback on whether team members felt their voices were being heard.

Common activities

Within the grade band groups, co-designers engaged in activities such as *The Five Whys* and *Systems Mapping* (Penuel and Gallagher, 2017) in order to better define and understand their PoP as well as attend to the system-wide nature of the task. The Five Whys activity took small groups of co-designers through a sequence of five questions to determine the key problem their collaboration is trying to solve. At each iteration the group would ask itself and respond to the question of *Why is this a problem*? Drilling down deeper into the roots of the PoP. The Systems Mapping activity began with envisioning a classroom in which the PoP had been solved. From there, co-designers would map this vision to other aspects of the classroom, the school, the district, and the state levels that were supporting this classroom. These two activities were utilized for creating a deeper understanding of the chosen PoPs and how these problems are both locally relevant as well as situated within the larger educational system.

Common participation structures

Knowing that we were designing a boundary encounter with a wide variety of educational communities present, the Project Team hypothesized that negotiations within Co-design Teams could involve power imbalances among members. In our collective experiences in leading professional development, we knew that classroom teachers often feel their voices are less important than district leaders and state education representatives. Further, we worried that researchers' voices may be given different weight than practitioners and planned a variety of participation structures to mitigate potential discontinuities. Steering Committee members decided which activities would utilize a *role alike* group structure (e.g., all district leaders in one group), a mixed group structure (e.g., teachers, district leaders, researchers), whole group discussion or a combination thereof. While some Steering Committee members were leading activities, others would listen to co-designers' conversations, attending to equitable participation. Periodically, co-designers were asked to reflect on whether they felt their voice was being heard in their Designer's Notebook which would be read daily by the Steering Committees.

Methods

The data used for the analysis in this article came from a variety of sources. To understand what co-designers identified as the artifacts and activities that facilitated choosing a PoP, we examined written reflections in all 60 Designer's Notebooks (20 Co-designers at each grade band). Specifically, we analyzed responses to the co-designers' explanations of their drawings for the following prompt completed at the end of each of the 3 days (see Figure 5 for an example): *Graph a "day in the life of a designer" on a set of axes and label the high and low points, with specific reasons for that designation*. Regarding Steering Committee members, the Project Team conducted Focus Group interviews with each of the three grade band Steering Committees using the same set of prompts, some of which asked them to reflect on their role in facilitating the summer retreat (see Appendix A for

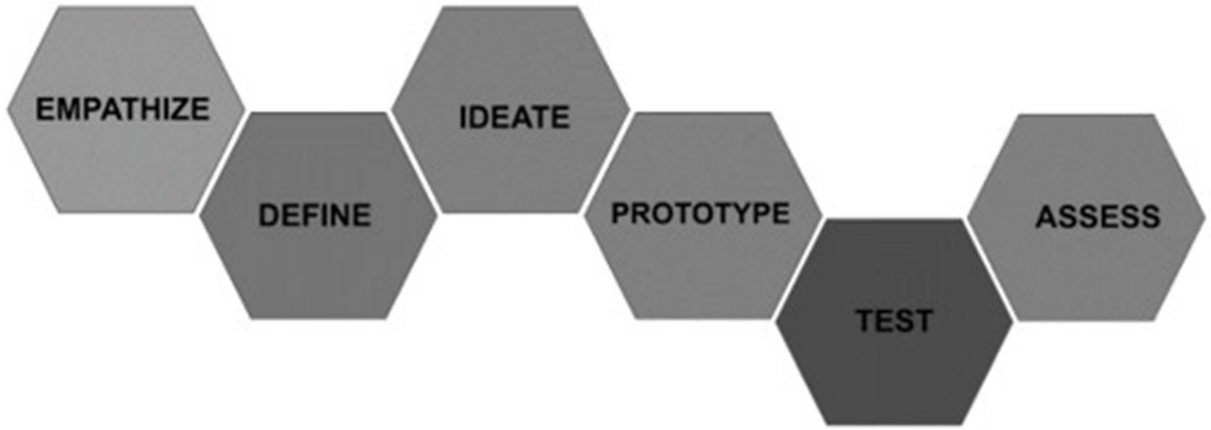

FIGURE 4
The design process (d.school, 2018).

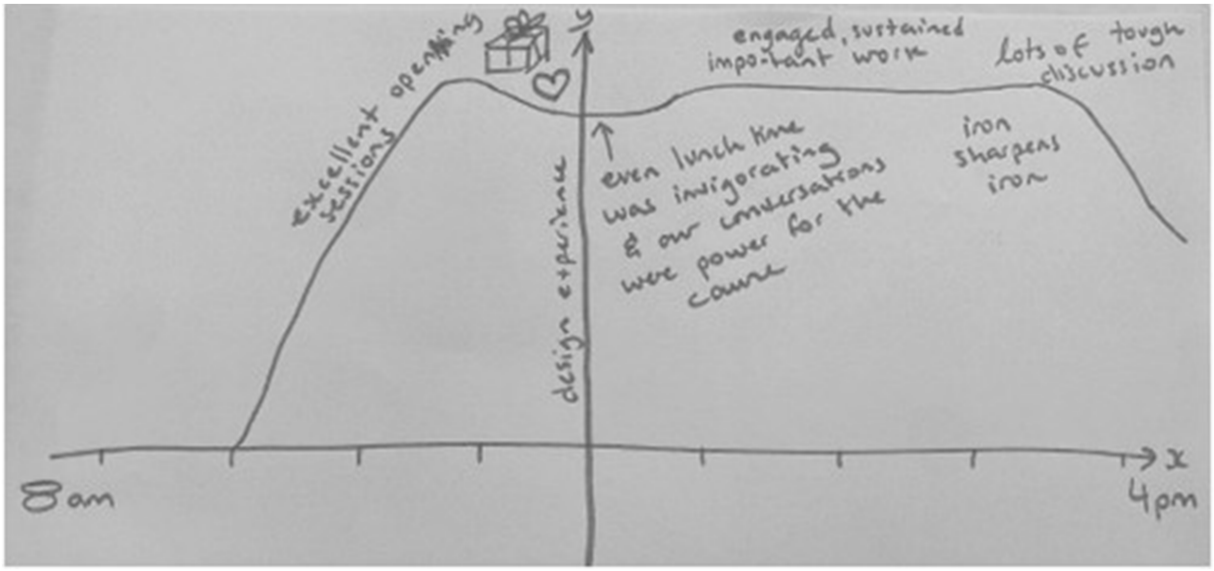

FIGURE 5
A day in the life of a designer example from a 6–8 co-designer, day 1.

specific questions). These interviews lasted between 30 and 45 min each. The focus group interviews were audio recorded and transcribed verbatim. Finally, each of the Project Team members responded to the same interview questions individually in written form, in an online format. Written responses averaged five pages per Project Team member.

To analyze the co-designers' designer's notebook data, a table was created for each grade band that included a row for each co-designer. For each row, we indicated the member's community (e.g., school based coach) and which activities or artifacts they listed as high and low points of design. Three researchers independently read co-designers' written elaborations on each of their high and low points. Coding for potential sources of discontinuity related to the two dualities (identification-negotiation and participation-reification). For example, "I left yesterday feeling like we talked in circles" would be identified as a potential source of tension. Each of the researchers noted activities and artifacts within the table and blinded their analysis to the other researchers. When each researcher had finished their analyses, we unblinded the table cells to look for patterns across co-designers' data within and across grade band teams. We used a constant comparison method (Strauss and Corbin, 1998) to look for patterns in both tensions and the artifacts and activities listed, noting counter examples as they arose and making refinements to our conjectures as needed. We then independently analyzed transcripts of relevant focus group interview questions (see questions 1–9 and 13–15 in Appendix A) in the same manner as we did responses in the Designer's Notebook to identify, from the Steering Committee members' views, what artifacts and activities were and were not supportive. In addition, we noted Steering Committee members' statements related to tensions they perceived during their sessions. Similarly, we each analyzed Project Team members' written reflections to the same prompts using this same method. While each of these was

being done, we kept individual notes about conjectured cross-group themes and met periodically to compare and revise conjectures until all data sources were exhausted. As a final step, we compared and reconciled notes concerning tensions reported either by Steering Committee or Project Team members. In this way, we identified discontinuities and supports that arose across all three grade bands as well as some that were unique to each. By leveraging multiple sources of data (i.e., data triangulation), multiple researchers completing comparative analyses of individual findings (i.e., investigator triangulation), and more than one context (i.e., three different co-design teams; environmental triangulation) we aimed to establish trustworthiness in our findings (Stahl and King, 2020). We acknowledge that our analysis is limited in that Co-designers may not have been as forthcoming with their frustrations knowing that their Notebooks were being read by leaders, some of whom may be friends. Additionally, some may have written responses less truthfully in order to been seen more positively by leaders. At the completion of the first draft of this manuscript, we shared it with all participants so that they could ensure we had represented their views accurately; we had no feedback that led us to revise the analysis. In what follows, we describe three common discontinuities that emerged as co-designers chose a PoP and the artifacts and activities that they indicated helped them work through differences.

Findings

We begin this section by presenting the problem of practice chosen by each grand band team as background for reading about the discontinuities found in our analysis (see Table 1). Then, we address RQ1 by describing the situations and conditions under which three common discontinuities arose multiple times in each of the three grade bands as they identified a statewide problem of practice to address (see Figure 6). To answer research question 2, we describe how designed artifacts and activities, what we refer to as researcher-imposed since they were introduced by steering committees, supported teams in working through each discontinuity. The analysis will highlight that there were artifacts and activities that arose during the course of the work as well, i.e., emergently designed. In the discussion section, we tie the emergence of these discontinuities to their relevant dualities and reflect on the learning that was thus made possible.

TABLE 1 **Problems of practice identified by each grade band co-design team.**

Grades K - 5 Not all education stakeholders have access to networking and rich learning experiences to develop and enact shared vision of teaching through problem-solving for each and every student to have conceptual understanding and proceduralfluency in whole number operations.
Grades 6–8 Due to o variety of individual, local and systemic policies, practices and visions, Instructional Leaders (ILS) have not been adequately equipped to support each and every teacher and student to flourish mathematically. Our co-design efforts will focus on creating, adapting, and/or providing access to resources, routines, and infrastructures for ILS to support their community to flourish mathematically. Furthermore, we acknowledge that minoritized communities are less likely to be supported to flourish mathematically so our co-design efforts will make this our priority.
Grades 9 — 12 An important aspect ofhigh-quality and equitable math instruction is the role ofmathematical discourse. Due to the perceived lack of a shared vision of the form andfunction ofmathematical discourse, our design efforts will focus on redesigning state and local systems ofinstructional support so that each and every student has the opportunity to learn andflourish through math discourse.

Discontinuity 1: frustration with the ambiguity of the design process

One discontinuity occurring across all three Co-design Teams involved the different ways in which members of the community typically experience collaborative work with colleagues. Engaging in the *researcher-imposed* design process was new for many of the Co-design Team members and caused some discomfort. As school and district leaders, they were well-versed in the practices of designing typical professional development in which the problem of practice was already defined by external groups or factors. Further, in many cases, the goals of the design were also predetermined. Even those participants who had engaged in the design process during earlier Mathematics Collaborative work were uncomfortable with the design practices introduced at the outset (Figure 4).

In a departure from team members' normative practice of creating resources and experiences to address *already established* goals, participants were asked to identify a problem based on statewide listening data which required spending significant time in the empathize and define stages. This aspect of collectively selecting the problem of practice was new for all project members and created ambiguity for Steering Committee and Co-design Team members alike. As one of the Steering Committee members explained in the focus group interview,

> *Normally you have a set of goals* [when designing PD]. *You know where you're going. You know where you're taking them, and that you achieved that. We don't know what we're going to create. We don't know our problem of practice yet. We're figuring it out as a team collectively going along this path. (K-5 Steering Committee member)*

Anticipating that this particular design process would be new for participants, the introductory session during the summer retreat included a visual image of the design process (See Figure 4) and activities to help participants think about the process. And yet, quickly upon breaking into grade band groups to select a problem of practice, the ambiguity, non-linearity, and slow pace of the design process created discomfort and, in some cases, frustration. Engaging in this design process provoked an identity crisis due to practitioners' design practices differing from those introduced for this project. In participants' typical experiences of design, a project such as this began with the creation of resources or learning experiences, the *prototyping* part of the process. Possibly expecting the same starting point, participants did not really consider the design work as having started since defining the PoP and empathizing with potential users lasted until the second and third

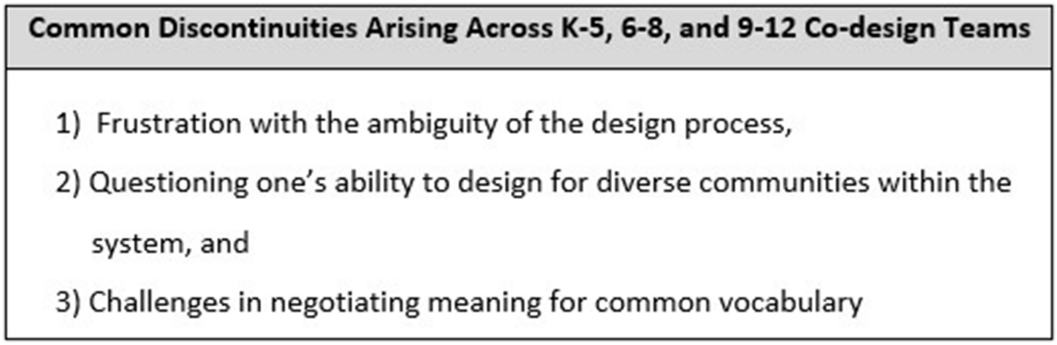

FIGURE 6
Common discontinuities arising across K-5, 6–8, and 9–12 Co-design teams.

days. Frustration among co-designers grew, with recurring calls to begin ideating. As one K-5 steering committee member recounts, "They're like, 'When are you going to tell us what to do? When are we going to start?'"

Artifacts/activities to facilitate progress for frustrations with ambiguity of design

We argue that this particular discontinuity arose, in part, due to the fact that researchers introduced an artifact and associated practices from a formal design community that did not align with the design practices of our co-designers' communities of practice. This identity-related discontinuity sparked a negotiation of what constitutes designing in this boundary space. Facilitators used two strategies to negotiate co-designers' discomfort with this design process. In the next sections, we elaborate each of these strategies and how they facilitated co-designers' progress.

Strategy 1: soliciting feedback on frustrations

The first strategy implemented by the Steering Committee and Project Leaders involved intentionally using formal and informal opportunities to *read the room* and understand how team members were feeling about the process. To gage team members' sense-making and feelings during the sessions, the Steering Committee asked co-designers to draw a graph of a *day in the life of a designer* in their Notebooks and explain high/low points each day. The daily graphs allowed Steering Committee members to understand when team members were frustrated and why. Generally, low points occurred when there was uncertainty about where the group was headed or how long the process was taking. Many were ready to get started creating resources. Evidence of this tension can be seen in the Day 2 reflections of one Co-design Team member who indicated that it was frustrating not to start the second day with a well-defined problem of practice (Figure 7).

> *However, I did struggle knowing that coming in today, we still did not have a problem of practice defined. I left yesterday feeling like we talked in circles, and the morning kind of started off that way as well (6–8 co-designer).*

For this co-designer, and others, the process of identifying and defining a problem of practice oscillated between an inspiring yet daunting activity and a frustrating, wordsmithing time delay. As another co-designer expressed, "I'm a doer!" Some Steering Committee members wrote back to their co-designers in the Notebooks, empathizing with their desire to move faster to the design stage.

A second strategy facilitators used to understand co-designer's feelings about the process involved engaging in informal communications with them.

> *I'll get a text sometimes after a meeting and be able to get a pulse on things. Well like there, there are some people that were really frustrated by this tonight, or some people are like walking away like not feeling great about where we're at…and those personal connections make the world of difference, because I know all three of us have had the moments where we get the text, or like the sidebar where we get someone telling us like this is, this is getting frustrated, or I'm not sure what's happening right now, or what am I supposed to be sharing? Um? I need to take a break, right? I need to step away. And I think that helps in sitting with the discomfort is that we have those personal connections, and all three of our [steering committee] networks are with different people (K-5 Steering Committee member).*

While these informal communications allowed Steering Committee members to provide reassurance to individuals and get a pulse on the group, they ran the risk of privileging some voices more than others. To attend to this potential threat, middle grades Steering Committee members, for example, deliberately positioned themselves at different tables in the room to hear the small group discussions and ensure that voices from quiet participants and those not sharing much in designer notebooks were being heard. As a result, the Steering Committee learned that multiple co-designers were becoming increasingly frustrated with the non-linearity and time-consuming design process. To initiate a re-negotiation of their role, a Steering Committee member addressed the *elephant in the room* on the morning of the third day by empathizing with co-designers. She positioned herself as an instructional leader who regularly designs professional development and stated that she too was uncomfortable with the process. She rhetorically asked them, "How many times have we had the privilege to pick our own problem to design for?"

> *Another critical moment was to distinguish between the design work of researchers and that of coaches/leaders. There had been*

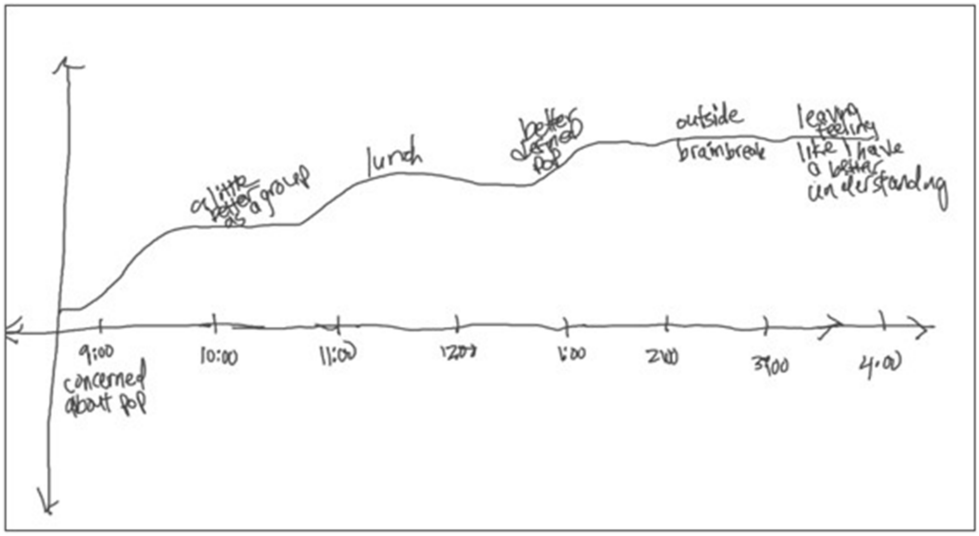

FIGURE 7
One co-designer's reflection on day two design work.

> *tension in the room about going slowly through the design process so [SC member who is a district coach and teacher] started off the third morning with a nice reflection on how teachers and leaders are used to someone giving them the "plan" for PD and that this is a privilege to get to do the type of work that we are doing this summer. We were very intentional about having a classroom teacher/leader share that reflection in the hopes it would calm the unease about not having created anything yet (6-8 Steering Committee member).*

Such facilitation moves and activities like positioning themselves socially and physically among the co-designers and analyzing reflections in Designer's Notebooks became particularly valuable to the Steering Committee in deciding next steps because these sources helped ensure that all team members had a voice in the process rather than just the ones who were speaking out in the sessions or texting informally between sessions. An elementary Steering Committee member noted,

> *That was really nice to read those [designer's notebooks] at night. However, because I mean, I think we have folks that are not going to speak out and not going to say anything, but they are willing to write in their designer's notebook and show their feelings. So, I think you know we get one text from a person that says they're frustrated. We think the whole crowd's frustrated, and that wasn't the case at all. I think we would read at night and say, "Oh, they have a better understanding than we thought of the problem of practice, or they were feeling better than we thought" (K-5 Steering Committee member).*

From designer's notebooks and informal communications, it became clear that many expected that the group would get through at least one full cycle of the design process in the 3 days of the summer retreat. Yet, it became apparent to them on the first day that the process was going to be much slower than anticipated, which caused frustration among some team members.

> *However, I did struggle knowing that coming in today, we still didn't have a problem of practice defined. I left yesterday feeling like we talked in circles, and the morning kind of started off that way as well* (K-5 co-designer)

> *I think it has been challenging to not come away with a solution, given all the discourse throughout the 3 days, but we knew we were just getting started and now have some direction to move forward.* (9-12 co-designer)

Reflections such as this confirm that co-designers continued to struggle with the slow pace of design, while simultaneously recognizing the need to carefully define the problem prior to designing:

> *We cannot craft PD, or really begin to determine resources without having a clear definition of effective mathematical discourse. (9-12 co-designer)*

> *The seemingly slow progress was well worth it. We did a lot of defining and thinking that allowed us to really dig in and move ahead. (6-8 co-designer)*

Strategy 2: continually mapping progress to the design hexagons

A second way we addressed this tension was to expand the use of the hexagon design process visual (Figure 4). Continually revisiting *the hexagons*, as they became known, served as a map of where the team was in the process before each activity. "I think this helped everyone have the bigger picture of the design process and know that we were making progress even if it did not feel like it," according to a Steering Committee member. By explicitly mapping progress on the image multiple times a day, team members began to understand that the design process was not linear and that just because the team had not reached the end of the process did not mean that nothing was being accomplished. Participating in conversations, whether through notebooks or in whole group, and mapping progress with the hexagons

led to a reification of the hexagonal design process in Figure 4. Notably, the hexagons and the design process it represents was imposed by researchers as a way to organize the joint enterprise of each grade band group. To our surprise, the hexagon image was taken up by Steering Committees as a reference tool for future Co-design work.

Some co-designers continued to struggle more than others, even with multiple conversations both in formal and informal spaces and continual references to the design hexagons. However, enough continuity was re-established by the end of the process for co-designers to begin the design phase after the retreat ended.

Discontinuity 2: questioning one's ability to within the system

As our teams worked to identify a problem of practice, they periodically revisited the design commitments and principles and PoP characteristics (Figures 2, 3) to remind themselves that the problem must resonate with multiple communities across the *state* educational system. Most members could identify problems of practice that were relevant to their own local context (one's own school or district) and found it challenging and uncomfortable to identify a problem beyond their immediate setting or role group. While our commitments to students, teachers, leaders, families, and district and state level mathematics education leadership were clearly stated, one of the common tensions that arose was how to think outside of one's own educational context in order to identify a PoP relevant to all mathematics educators. We refer to this as engaging in a practice called *systems thinking*, thinking about how the PoP might be taken up by others across the state system. Co-designers across all three grade bands expressed discomfort with designing for stakeholders from other educational communities, particularly with those that did not have representation in the room (e.g., parents and students). This commitment to represent the ideas of everyone across the system, not just one's own context, was a constant tension arising from the discomfort involved in representing unfamiliar perspectives across the system.

Artifacts/activities to facilitate progress for designing for a state system

Our analysis indicated that there were two supports that helped co-designers work through discontinuity two. First, Steering Committee members asked co-designers to consider the diverse needs of stakeholders across the system utilizing role-alike, mixed group and whole group participation structure. Second, they implemented an activity that we called systems mapping which asked Cosigners to envision which stakeholders across the system have an impact on their practice.

Strategy one: role-alike, mixed group, whole group participation structure

The first designed support that facilitated perspective-taking involved a particular participation structure: discussion in role-alike groups followed by mixed-role groups where co-designers were asked to share their perspectives and consider other perspectives across the system. For example, in the 9–12 meetings, co-designers were placed in role-alike groups and asked to consider how the proposed PoP applied to their role, what they saw as the biggest challenges in addressing the PoP, and what other groups will see as the biggest challenges to overcome. Then they switched to mixed groups where they shared what their role-alike group discussed, integrated the different role-group members' points of view, and considered how this added to their understanding of the PoP. Finally, the co-designers met as a whole group to discuss what they learned about other groups' perspectives of the PoP and generated a list of additional groups that needed to be considered as they continued the work. One co-designer noted,

> *Getting to first talk with our "like" groups made me feel like I was not alone in my thoughts. It made me realize that we have similar thoughts and concerns. Getting to take ideas from our "like" groups to the "mixed" group was eye opening because there are so many factors/stakeholders/concerns that I don't consider on a daily basis (or ever) (9-12 co-designer).*

For this co-designer, this participation structure was key to understanding the perspectives they had not considered prior. Many of the co-designers had similar reactions to the structure stating that it helped them understand how their concerns were related to those of others in the system that they had not thought about before. A Steering Committee member recalled, "A team member from a very different teaching context expressed she did not feel like she was part of the group because we were not considering her context. This was important for the group because it reminded us that we are designing for all educators, not just ourselves." While the participation structure seemed to be a powerful one for considering others' contexts in relation to a PoP, some co-designers continued to live in discomfort noting how overwhelming it was to consider the needs of an entire system.

> *The lowest point was when we were sharing after our role-alike sessions about how this applies to our role, the biggest challenges, etc. because the task became overwhelming when thinking about how much work there is to be done and how we can feasibly do this while attending to all of the various challenges (9-12 co-designer).*

For this co-designer, becoming aware of how a PoP poses challenges for others in the system was overwhelming and led to significant concerns about how we could possibly design for a PoP to attend to all stakeholders in the system. This concern was still strong among other Co-designers at the end of the summer retreat and prompted them, later in the design process, to try new designs with a variety of mathematics educators before finalizing them.

Strategy two: systems mapping activity

One activity that emerged as significant in negotiating the tension of systems thinking was to develop a systems map. All three grade band teams engaged in the systems mapping activity but adapted it according to their needs at the moment. Originally, co-designers were going to be asked to draw a map placing the mathematics classroom in the center of the state system and then draw nodes and connectors for all of the people that have an influence on their daily practice and on whom they have an influence. However, two grade bands slightly altered the activity by changing who was at the center. The K-5 team placed the classroom in the center (as originally intended), and the 6–8 and 9–12 teams placed the words instructional leaders or myself in the center, respectively (see Figure 8). Although the systems mapping activity was imposed by the Project Team, it was mentioned as a high point in many of the Designer's Notebooks as it highlighted

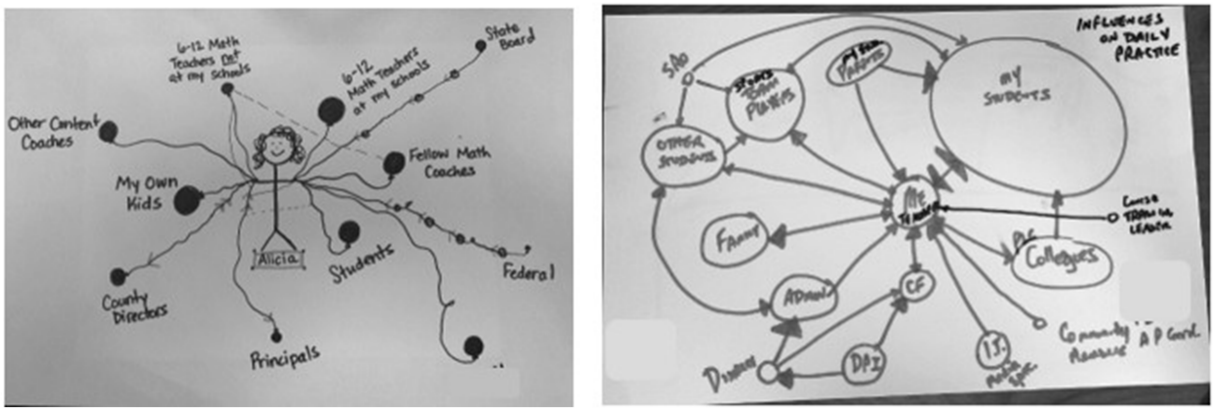

FIGURE 8
Sample systems mappings from the 9–12 Co-design team.

how each of the co-designers was a part of the system and where they had influence, a perspective that many, especially the school-based teachers and teacher leaders, had not considered before. In the words of one 6–8 co-designer, "[a] positive experience [today] was first seeing how others in different roles viewed the problem of practice and how they created the systems mapping from their perspective. At the same time, it was neat to see how similar the mappings were, but different language was used".

The importance of considering the system as a whole quickly became a central component for all Co-design Teams as they worked toward articulating a PoP. The 9–12 co-designers, in particular, shifted their focus to unpacking the potential impact of the PoP across the system which led to discussions that included unintended outcomes, resources that might be needed, and how to develop common language for the problem. This brainstorming was done using large sticky notes around the room, which were then organized by theme. The Steering Committee then took the ideas that emerged from the sticky note activity and represented them in a rainbow shaped figure. The rainbow illustrated the different nested roles across the system as well as the importance of clearly articulating a message about the PoP (Figure 9).

When reflecting on this activity one of the Steering Committee members shared:

> *I remember all of us being very excited … I remember taking the sticky notes off the board of what everyone had said that day, and started laying them on the rainbow. It was helping us organize the work and the ideas people had. And I remember all of us just started talking about if we are designing it for all of these different levels, it's a system. We can't just focus on one group, and even though we are focused on instructional leaders, we need to be thinking about their work with principals and their work with teachers. And we can. The picture was so inspiring* for *us (9-12 Steering Committee member).*

The rainbow diagram was then introduced to co-designers to consider the ways it captured their ideas, how components of the rainbow might be defined, and how it could inform their work together. A Steering Committee member later explained, "it helped us both identify target audiences and connections among them, while also maintaining the complexity of the interdependent subsystems." Throughout this process the co-designers began to refer to the diagram as the rainbow both within the team and when describing team progress to the other grade band teams, indicating that it represented a reification of the systemic considerations of their PoP.

Discontinuity 3: challenges in negotiating meaning for common vocabulary

In the process of identifying a problem of practice, all three teams found that individuals held differing, sometimes problematic meanings for key terms used to describe their PoP. In the elementary room, it became clear that meaning for the terms *procedural fluency* and *problem solving* was not shared among co-designers. In middle grades, *equity* was problematic and in high school, *mathematical discourse* needed clarification. All of these terms are common in the mathematics education community and served as a starting point (continuity) for defining a PoP. However, very quickly, it became clear that members did not share meaning for these terms and, indeed, they each have nontrivial meanings within the mathematics education community. All terms are integral to each PoP description and would need to have shared meaning for the design process to be effective. Steering Committee members had to assess the disparate meanings among co-designers and decide when and how to address diverse interpretations of the terms. In addition, they had to attend to the way power was distributed across co-designers as they engaged in these negotiations of meaning. In other words, Steering Committee members needed to ensure that all individuals' opinions were considered and that members from majority groups with more perceived, or real, power did not dominate negotiations.

Artifacts/activities to facilitate progress in negotiating meaning of vocabulary

Our analysis indicates that through co-designers' participation in a variety of defining activities, meaning for key terms became reified either during the retreat or in meetings afterward. Each Steering Committee conducted these negotiations differently, but all did so through what we call *defining activities*. The high school co-designers had multiple defining discussions using the role alike, mixed group, whole group structure and asked their project leaders to concretize

FIGURE 9
The initial "rainbow" used to describe the relationships among the sticky note ideas.

their meaning into a mathematical discourse document. The elementary group asked co-designers to draw a picture of a classroom that resembles their vision of HQEMI and then to label their pictures with the terms *problem solving* and *fluency*. The picture activity and subsequent gallery walk were instrumental in creating shared meaning for those terms (Baker et al., 2025).

The middle school group had a particularly unique challenge defining what they meant by equity in mathematics classrooms and used a variety of participation structures, artifacts, and activities to create a shared definition. The uniqueness of this challenge lies in the fact that equitable mathematics instruction has yet to be well-defined by the mathematics education community. In addition, conversations about equity in education include explicit attention to the individual and systemic harms perpetrated on minoritized students and teachers and elicit strong emotions. However, there was an immediate call by co-designers on day one to define the term. Multiple participation structures were used throughout many *defining discussions* across the 3 days and included (a) think-pair-share, (b) role alike-mixed-whole group and (c) whole group. By the end of day two, there was still no consensus with one co-designer writing, "I feel like we have different visions around meeting the needs of our diverse students".

Some middle grades Steering Committee members heard conversations among different subsets of the Co-design Team that seemed to trivialize notions important in defining equity and noticed that most were not attending to the experiences of minoritized students. The Steering Committee convened at the end of day two and designed a new activity that they hoped would center the voices of minoritized students who are not typically supported in mathematics classrooms. The next morning a facilitator began the session with the question, "Which students are not being supported to flourish in mathematics? Let us name them and I'll start. Students who are Black and Brown." Co-designers began naming other student populations and, when the list was exhausted, met in table groups to generate descriptions of what mathematics classes would look and sound like if these particular groups of students were flourishing. These whole and table group conversations were pivotal in surfacing that we did not share a definition for equitable mathematics instruction after attempting to do so for 2 days. We recognized that even the mathematics education field does not share a definition and thus abandoned the difficult task of clearly defining equitable mathematics instruction. Instead, the 6–8 team thought a more productive activity would be to create a Planning, Enacting, and Assessing for Each and Every Student to Flourish document which described characteristics of instruction that would support students, in particular minoritized students, to flourish. One of the Steering Committee members noted,

> *…when we started naming all of those [minoritized students], then it started becoming a little bit more deeper. And that, to me, at least, felt [like] more meaningful conversation. And I think that kind of shifted the way we thought about what we mean by equitable (6-8 Steering Committee member).*

The co-designers drew on and possibly grew their personal identities through mutual engagement with community members. In doing so, their negotiations of meaning for key terms led to reifications of those meanings into community artifacts (e.g., Planning, Enacting, and Assessing document). As a consequence of defining activities and utilizing a variety of participation structures, each grade band team negotiated meaning for key terms resulting in reifications that carried shared meaning. Notably, the defining process was not trivial and extended beyond the summer retreat; yet, each grade band re-established continuity and meaning for key terms in their PoP enough to start designing after the retreat.

Discussion

Research designs that position practitioners as genuine partners in defining their own problems and solutions democratizes the research process thereby strengthening the potential uptake of research results (Penuel et al., 2015). With that being said, research-practice partnerships create boundary encounters that can be tension

filled, with partners negotiating meaning by drawing on sociocultural practices that can be both complementary and somewhat at odds with each other. These sociocultural differences often interrupt the design process and do not automatically create opportunities to learn. The Mathematics Collaborative partnership presented a unique case to understand what discontinuities arise when designing for boundary encounters involving participants (a) representing a large variety of education communities (a constellation) and (b) defining their own problems of practice at state scale. In this paper, we analyzed data from multiple sources and participants' viewpoints to understand what discontinuities arose during the early stage of collaborative design focused on problem definition and what supports enabled the work to continue. Our data analysis was focused exclusively on the discontinuities that were common across each of the three co-design teams so that others who engage in designing for systemic solutions (in this case, a state educational system) can plan supports for similar discontinuities that are likely to arise in their work. We identified three discontinuities experienced when members of different communities from a constellation of interconnected practices engaged in a boundary encounter to define a problem of practice: (1) Frustration with the ambiguity of the design process, (2) Questioning one's ability to design for diverse communities within the system, and (3) Challenges in negotiating meaning for common vocabulary. In addition, our analysis identified several artifacts, activities, and participation structures that proved useful in productively engaging with and resolving these discontinuities. In the following sections, we return to Wenger's (1998) constructs of constellations of interconnected practices and two learning mechanisms – participation-reification duality as meaning making within a community and identification-negotiation duality as the formation of identities in relation to a community. We argue that these dualities surfaced discontinuities that were somewhat unique to a state-wide constellation and that certain forms of support were helpful in surfacing and resolving them during collaborative design.

As representatives from different communities within a constellation of interconnected *practices, discourses, and histories*, these participants' similarities in practice and identities initially seem to serve as continuities that enabled the teams to begin the work of identifying and defining a shared problem for the constellation. By virtue of being a part of the same state education system, participants in this study shared a history of practice, goals of improving mathematics teaching and learning, and elements of their discourses as mathematics educators. Co-designers shared a general understanding of the state education system in which they worked and their role in that system. All had experience designing materials and environments to support professional learning. They were familiar with and used words like *fluency* and *discourse* in their professional conversations. As continuities, these common elements in their practices and discourses facilitated team members' initial engagement in developing empathy and defining a systemic problem of practice for their grade band team to address. For individual co-designers, their shared identities as mathematics educators working for more equitable and just mathematics learning for children created space for listening to perspectives from other levels of the system, articulating nuances from their own perspective, and negotiating new understandings of themselves in relation to the team and the roles they might play in its work together.

At the same time, the practices of one community in a constellation are different from another community's practices. Though interconnected, the practices of a community are nevertheless distinct, with meanings tied to their unique educator identities and their understandings of other communities in the constellation. This diversity of practices, meanings and identities caused discontinuities to arise, and thus opportunities for both collective and individual learning to occur. In a boundary encounter of diverse communities within a constellation, we contend that Wenger's (1998) two fundamental mechanisms for learning in a community of practice – negotiation of meaning and formation of identities – amplified and interfered as members of distinct communities engaged with one another in ways that surfaced unique forms of discontinuity. For example, tensions associated with the identification-negotiation duality caused an interruption in the design process when co-designers questioned their ability to choose a problem that would resonate with educators across different levels of the state system. However, through a variety of participation and reification events, co-designers were able to resolve their identity crises through negotiations with members from different role groups. Thus, a discontinuity rooted in the identification-negotiation duality resolved as co-designers' identities shifted from a designer of problems for their local context to a co-designer who empathizes for and chooses problems that resonate with others outside their role specific group.

Co-designers' identities were constantly challenged and re-negotiated within this RPP as they engaged in defining key mathematics education terms such as fluency and discourse, confronted their own biases and beliefs associated with equitable mathematics, and met in cross role groups. In each of these types of events, unacknowledged power imbalances may have influenced co-designers' participation as well as sense of belonging in the RPP. Recognizing the value of power dynamics in RPPs is essential for unearthing equity-oriented boundary negotiations and the practices that cultivate equitable participation (Farrell et al., 2023; Wegemer and Renick, 2021). While our analysis did not attend deeply to issues of power, we have some evidence that some co-designers felt power imbalances particularly when cross role group discussions occurred (teachers felt intimidated by district level leaders who, in turn, had similar feelings toward members of the state education agency and researchers). Activities such as systems mapping, role alike and cross role meetings, and checking in with co-designers through formal and informal communications were conducted as a way to support co-designers in renegotiating their membership and identity within the group. In addition, positioning practitioners as co-designers who would choose a problem of practice rather than be handed one in a top-down manner may have supported more equitable participation as well as increased power and agency among practitioners.

By engaging in levels of participation and reification events, the constellation also negotiated shared meaning for key mathematics education terms, resulting in important reifications of that collective meaning. Take for example, the discontinuity experienced by the 6–8 co-design team related to the realization that equity did not have the same meaning for all team members. Co-designers asked to define the term as soon as equity was chosen as the problem of practice, and it wasn't until the last day of the retreat when they decided to reify their understandings of equity in a Planning, Enacting, and Assessing for Flourishing document. The same happened for K-5 and 9–12, with reifications arising through various participation events. This shift in

enterprise, defining key terms and reifying their meaning in concrete objects, illustrates the collective learning of the constellation.

Discontinuities in boundary encounters can be generative sites of learning (Akkerman and Bakker, 2011; Wenger, 1998). Our analysis identified various artifacts, activities, and participation structures that facilitated teams in engaging with and resolving these moments of interruption. For example, introduced or newly produced artifacts such as the hexagons and the rainbow diagram, respectively, were in-the-moment reifications of the teams' new understandings of the design process and problem space. Activities such as systems mapping provided a context for co-designers to make their current understandings of the problem of practice public for the team and to engage with others' meanings. Structures for participating in the teams' efforts to define their respective problems such as the role alike - mixed group - whole group structure supported co-designers in clarifying and legitimizing their unique contributions to the team, coordinating their respective community's practices with communities across the constellation, and negotiating nascent ways of participating and being in relation to the team (Akkerman and Bakker, 2011).

For large, multifaceted RPPs and other collaborative design efforts, Wenger's (1998) notion of a constellation of interconnected practices proved to be a theoretically and practically useful frame to understand how stakeholders from multiple similar-yet-distinct communities come together to negotiate a shared focus for collaboration. Theoretically, the construct highlights the relationship between the number of interconnected practices present in a boundary encounter and the potential for new forms of discontinuities of practice. Such moments of experienced discontinuity can provide more occasions for collective and individual learning, especially with support to represent, engage with, and negotiate new and shared meanings. Similar to other researchers examining learning in boundary encounters and during collaborative design, the discontinuities highlighted in this study were occasions for learning (Akkerman and Bakker, 2011; Engeström et al., 2015; Wenger, 1998). At the same time, the idea of a constellation of interconnected practices draws attention to the continuities of practice that relate the communities of a constellation. Similar high-level goals, shared identities, and common elements of discourse afforded by related practices enable individuals from distinct communities in a constellation of practices to engage with one another, identify with a broader collective, realize distinctions among their practices, and coordinate with others.

Conclusion

In this article, we used the ongoing work of the Mathematics Collaborative research-practice partnership to identify discontinuities that arise when bringing together individuals from multiple educational communities to engage in joint work around a shared state-wide problem. We described three discontinuities that were common across three co-design teams and reflect the inherent tensions that individuals experience in boundary encounters with community members that represent a large number of interconnected, yet different education communities. We argued that, if discontinuities are to be effective learning opportunities, project leaders must carefully design supports for the discontinuities they expect. We then presented the specific artifacts, participation structures and activities that enabled our co-designers to work through their differences in the hopes that others who want to engage in design at state scale learn from our findings.

Data availability statement

The anonymized raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of North Carolina Greensboro Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MS: Writing – original draft, Writing – review & editing. AM: Writing – original draft, Writing – review & editing. CS: Writing – original draft, Writing – review & editing. HW: Writing – original draft, Writing – review & editing. KM: Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1628023/full#supplementary-material

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