Professional Learning through Collaborative Curriculum Design in a Research-Practice Partnership

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Abstract

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The purpose of this dissertation research is to understand the complex processes that unfold during collaborative design of reform-oriented science curriculum materials within the structure of a design-focused research-practice partnership (design-RPP). In particular, this research examines professional learning opportunities for teachers, collaborators, and researchers that are offered within the context of a design-RPP. Research-practice partnerships are becoming a common collaboration model in education, in particular when the goal is the design of curriculum innovations. With this model, partners may be brought together in inter-institutional and cross-practice collaborations known as design-focused research-practice partnerships (design-RPPs) to engage in joint work.

Theoretically, this research draws on sociocultural theories and conceptual frameworks of workplace learning, collaboration, and design processes to investigate how design-RPPs may function as contexts for professional learning. As a design-based research study, this research is concerned with how members of a design team engaged in iterative cycles of co-design, enact, and redesign as they created three curriculum units for high school science courses. Design tensions surfaced in this collaborative work; three tensions are explored in the empirical chapters included in this dissertation.

Methodologically, this research presents a synthesis of relevant literature along with two ethnographic case studies and a design narrative focused on collaborative work practices among the members of a design-RPP over a three year period. The first case study explored the tension of coordinating work across the multiple institutions that made up the design-RPP by centering the experience of a collaborator who took on different roles as the needs of the project and partner institutions shifted. This case showed that there may be a threshold for role fluidity which marks the number or types of roles an individual may be able to productively balance and that role porosity and re-mediations takes opportunity, trust, support, as well as time to develop. The second case study explored the tension of partnering with early-career teachers by focusing on professional learning as reported by a second year science teacher as she engaged in collaborative practices related to the design and enactment of high school biology curricula. This case study suggested that a design-RPP can function as a context for teacher professional learning and the development of multiple forms of expertise by serving as designer setting, in which a teacher's professional learning pathway includes activity structures and opportunities for learning that are unique to co-design work. The involvement of early-career teachers in intensive design-RPP initiatives needs to be undertaken carefully, with an acknowledgement that special routines and supports may need to be developed. Finally, the design narrative explored the design tension of how to select anchoring phenomenon for a contemporary and authentic project-based learning experience that meets shared goals. This narrative shared the experiences of a design team as they engaged in different activity structures to seek out needed forms of expertise while developing criteria for selecting anchoring phenomenon. Through cycles of knotworking, ad-hoc groups with specific forms of disciplinary, pedagogical, and design expertise and diverse cross-disciplinary expertise came together as needed to develop ideas, provide critical feedback, and engage in design and enactment work. The underlying connections between the members of the collaboration allowed for the design team to expand and contract as needed through the process of developing criteria for phenomenon selection.

Through this research, a new conceptual framework—the Framework for Professional Learning through Design in Partnership—was developed for understanding how professionals learn through collaborative curriculum design activities within the designer setting offered by a design-RPP. This dissertation seeks to contribute an understanding of how professionals learn while engaged in collaborative design of reform-oriented science curriculum materials within the structure of a design-focused research-practice partnership.

Table of Contents

List of Figures

List of Tables

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Though a dissertation is solo-authored, the focus of this work—co-design of curriculum within a research-practice partnership model—is by its very nature deeply collaborative. Throughout this document are references to the work of my close collaborators at the Institute for Science + Math Education: Dr. Elaine Klein, Dr. Veronica Cassone McGowan, Dr. Deb Morrison, and Dr. Philip Bell. The data corpus from which this dissertation pulls includes data collected collaboratively with Dr. Klein and Dr. McGowan, and some ideas and findings that are included within these chapters originated from these collaborations. I am deeply grateful to this team and their mentorship.

I gratefully acknowledge the teachers, collaborators, and students who participated in this research study. My work attempts to center their voices and experiences as educators and learners and is driven by a desire to create more authentic, relevant, and engaging science learning experiences through curriculum design and research.

My former colleagues at the Institute for Science + Math Education have offered friendship and mentorship over the years. Thank you all. Dr. Jeanne Ting Chowning was my amazing writing partner; her insightful feedback and support were critical to this work. I am especially grateful for the opportunity to collaborate on research projects with Dr. Veronica Cassone McGowan, Dr. Elaine Klein, Dr. Déana Scipio, Fan Kong, and Dr. Deb Morrison. In addition, I have learned much from my ISME colleagues Heena Lakhani, Gina Tesoriero, Dr. Enrique Suárez, and Nancy Price. Beyond ISME, Dr. Nathanie Lee Priddy offered friendship and advice, for which I am grateful. Thank you to Janneke Petersen for computer/formatting help.

I maintained a part-time job at the Center for Neurotechnology while attending graduate school. It was here that I expanded my understanding of the "E" in STEM education. I am especially grateful for many years of mentorship and collaboration from the ever-talented Dr. Eric Chudler.

I honor my health team at the University of Washington Hall Health and my hand therapist Maggie for their support and care.

(Deep breath). I hold in my heart two people who passed away during my graduate school tenure. My mother, Phyllis Nelson, taught me how to set goals and work tirelessly toward them. Her love and curiosity for the natural world is undoubtedly what sparked my early interests in science and set me on this path. My father-in-law, Marc Bergsman, was a deeply kind man who would have been so proud of me. I miss them both dearly.

With an open and grateful heart, I acknowledge my family, including extended family and close friends. A great big thank you to my husband Ryan Bergsman, for his love and respect, for believing in me, and for taking such good care of our family. He is an incredible (and patient) partner. Thank you to my daughter Clementine Bergsman, who grew from one to seven years old in the time it took me to apply for graduate school and accomplish my doctorate. No one could ask for a better cheerleader or source of inspiration. Thank you for being so patient while mommy worked on her writing. Thank you to my mother-in-law, Binky Bergsman; I could not have done this without her offers of childcare, home-cooked meals, and friendship. Thank you to my father, Chuck Clapper, for always believing I could accomplish what I told him I was setting out to do. I love you Dad. And thank you to Stanley dog, for our long walks together as we circled around the sun together. He is a very good boy.

This work is funded by the National Science Foundation through the STEM+C Program under grant 1543255. However, all opinions are strictly my own.

Dedication

I dedicate this work to my husband Ryan and my daughter Clementine.

Clementine makes the world shine brighter and inspires me every day in my work.

In memoriam of Phyllis Jean Nelson and Marc Elliott Bergsman.

Chapter 1: Introduction

Study Rationale

Research-practice partnerships are becoming a common collaboration model in education, in particular when the goal is the design of curriculum innovations. With this model, partners may be brought together in inter-institutional and cross-practice collaborations to engage in joint work. The purpose of this dissertation research is to understand the complex processes that unfold during collaborative design of reform-oriented science curriculum materials within the structure of a design-focused research-practice partnership (design-RPP). In particular, this research examines professional learning and the engagement of early-career science teachers in these kinds of collaborations.

The context for this work was the Computational Science Project (CSP)[1], a design-focused research-practice partnership that brought together partners from a school, district, educational non-profit organization, and university, along with external collaborators including disciplinary experts. The tenants of design-based research (The DBR Collaborative, 2003) guided the design of the CSP partnership, the curriculum products it produced, and CSP research endeavors. The CSP had the goals of creating a collaborative model for the design of curriculum, employing that model for the development of computationally-rich high school science curricula, and studying teacher, student, researcher, and scientist learning through this complex and highly collaborative work.

With this dissertation, I sought to understand CSP partnership dynamics, the emergent institutional, sociocultural, and professional boundaries, and design opportunities and tensions, and how these were negotiated through boundary spanning, the development of boundary

[1] All institutional names are pseudonyms.

practices, and joint work. I also sought to understand how members of the partnership engaged in professional learning through their participation in collaborative work, and what forms of expertise and changes to professional practice they developed.

In this introductory chapter, I introduce some of the partnership challenges and successes, design tensions and alignments, and opportunities for professional learning that emerged through partnering processes and two models of collaborative curriculum design (co-design). I interrogated the literature around these concepts in Chapter Two, which presents a synthesis of existing research specific to co-design and professional learning and identifies opportunities for further research. Three empirical chapters follow, each which explores a tension that emerged through the CSP partnership work. The three empirical chapters are guided by these research questions:

- **Chapter Three,** "Role Fluidity Across (Im)Permeable Boundaries of Partnership: A Case Study of a Boundary Spanner within a Research-Practice Partnership" asks: What roles did a person positioned as a boundary spanner take on in a design-based RPP, and who benefited from her participation? How did she cross the boundaries of the respective institutions in the partnership and in what ways was she constrained in this work?
- **Chapter Four,** "Professional Learning of an Early Career Science Teacher through Co-Design in a Research-Practice Partnership", asks: How did the involvement of an early-career science teacher in co-design, local adaptation, and reflective enactment of curricula benefit and challenge her professional learning, development of various forms of expertise, and professional practice? Should early-career teachers be asked to take on critical partner roles in design-RPP endeavors?

- **Chapter Five,** "Navigating Tensions in Co-design through Knotworking: Selecting Contemporary Scientific Phenomena for High School Biology Curriculum", asks: What processes and criteria for phenomenon selection should be used for the design of high school biology curricula? In particular, what selection criteria and processes of selection would support the design of curricula focused on a contemporary, locally-relevant, and computationally-rich scientific phenomenon that engages students in the socio-scientific issues of global climate change and evolution?

Theoretical and Conceptual Landscape

The CSP research team held a sociocultural perspective on learning. We understood learning to be socially, culturally, and historically situated (e.g., Bell, Tzou, Bricker, & Baines, 2012; Holland & Lave, 2009; Lave & Wenger, 1991; Rogoff, 1997; Wenger, 1998). It is through our sociocultural stance on learning that we considered the complex interactions of the CSP partners within our collaborative work, across multiple spaces and scales. In the empirical studies contained within this dissertation, I leveraged sociocultural theories, including Edwards' (2005, 2011, 2012) relational turn in cultural-historical activity theory (CHAT), social practice theory (Bell, Tzou, Bricker, & Baines, 2012; Dreier, 2016; Holland & Lave, 2009; Penuel, 2014), and practice-oriented professional learning pathways (e.g., Bell, Tzou, Bricker, & Baines, 2012; McDonald, Kazemi, & Kavanagh, 2013; Penuel, DiGiacomo, Van Horne, & Kirshner, 2016).

Across the studies that make up this dissertation, Tatar's (2007) design tensions framework was a helpful conceptual tool. In order to understand the multiple roles assumed by an individual within the partnership, in Chapter Three, my analysis is guided by the concepts of the articulation process of work (Strauss, 1988), boundary spanning (Akkerman & Bakker, 2011;

Ford & Youngs, 2017; Penuel, Coburn, & Gallagher, 2013; Penuel, Bell, Bevan, Buffington & Falk, 2016; Russ, Sherin, & Sherin, 2016; Wenger, 1998), and role re-mediation (Bang & Voussghi, 2016). To understand professional learning and development of expertise among a novice science teacher, in Chapter Four important analytical concepts include expertise with core teacher practices (e.g., Grossman, Hammerness, & McDonald, 2009; Grossman & McDonald, 2008; McDonald, Kazemi, & Kavanagh, 2013; National Academies of Sciences, Engineering, & Medicine, 2015; Franke & Kazemi, 2001 as cited in Russ, Sherin, & Sherin, 2016), computational inquiry (Jacobson & Wilensky, 2006; Sharples et al., 2015; Weintrop et al., 2016; Yoon, Goh, & Park, 2017), curriculum design (e.g., Brown, 2009; Huizinga, Handelzalts, Nieveen, & Voogt, 2014; Voogt et al., 2015), repertoires of practice for collaboration (Edwards, 2005, 2011, 2012), and professional learning through community (e.g. National Academies of Sciences, Engineering, & Medicine, 2015; Little, 2002, 2003). In Chapter Five, key concepts included phenomenon-driven science instruction (e.g., Suárez & Bell, 2019), computational and systems thinking in science classrooms (e.g., Weintrop et al., 2016), collaborative curriculum design in design-RPPs (e.g., Linn, Songer, & Eylon, 1996; O'Neill, 2016; Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013; Severance, Penuel, Sumner, & Leary, 2016), and the concepts of knotworking (Engeström, 2008) and mycorrhizae (Engeström, 2007, 2008).

Research Design & Methods

As a design-based research study (Bakker, 2014; Bell, 2004; The Design-based Research Collective, 2003), the CSP was concerned with studying the iterative cycles of co-design, enactment, and redesign of computationally-rich science curriculum materials. Research questions for the project as a whole centered on professional learning of teachers and disciplinary experts through engagement in co-design, as well as students' learning of computational practices as they relate to science investigations (Computational Science Project, 2015).

For the thread of research investigated in this dissertation, I employed the methodologies of case study and ethnography. Case study research methodology (Gay, Mills, & Airasian, 2012; Geertz, 1973; Stake, 2005; Yin, 2014) was employed in Chapters Three and Four as a way of providing richly descriptive cases of the professional learning trajectories and experiences of key members of the CSP partnership. Single case study methodology (Yin, 2014), especially when person-centered and combined with ethnographic field methods, provides a powerful approach for developing deeply descriptive accounts of a person within a larger context. Chapter Five shares a design narrative, a type of case study, and a set of design principles (Bell, Hoadley, & Linn, 2004; The Design-Based Research Collective, 2003). Ethnographic research methods allowed for the development of design knowledge, including design principles, design narratives, and the articulation of design phenomena. Design narratives are rich descriptions of the context, tools, activities, practices, assessments, and outcomes of DBR studies (Bell, Hoadley, & Linn, 2004). These types of narratives capture the stories of collaborative design partnerships. Design principles, a type of analytical generalization, are often produced in DBR studies to describe the "substantive 'what' and the methodological 'how' of the intervention" that may be helpful for researchers working in other contexts (van den Akker, 2013, p. 67).

Data Collection & Analysis

The data table provided in *Appendix A* provides a summary of the full data corpus that made up the three research studies in this dissertation. For each of the three empirical chapters, it provides the analytical questions that guided data analysis, as well as the key data sources and the methods of data analysis. Key data in the data corpus included field notes, video and audio recordings, and analytical memos from the following data sources: semistructured interviews, classroom observations, design sessions, planning meetings, work group meetings, instructional artifacts, and project archives.

Human Subjects Approval

This dissertation research pursues a thread of interest within the larger Computational Science Project data corpus. The CSP was granted exempt status from an Institutional Review Board. Though it was not required by the Board, the researchers obtained consent from participants in the project (i.e., teachers, scientists) to participate in its research aspects and obtained assent and parent permission from students in the enactment classrooms. Data collected on participants who did not return signed research forms was excluded from my analyses.

Study Context

In this section, I provide background information about the Computational Science Project, the design-RPP that was the context for this research. I provide information about the partnership, its member institutions, and a general timeline of partnership activities over its first three years. I also explain the two models of collaborative curriculum design that were developed and enacted through the CSP to design three high school science curriculum units. Additionally, I provide information about the participants who are featured in the research studies that make up this dissertation.

The Computational Science Project

The Computational Science Project (CSP) was a curriculum design and research initiative funded by the National Science Foundation focused on the inclusion of computational inquiry into secondary science classes. The project was originally funded for three years, but extended to four years with a no-cost extension to focus on preparing curriculum products for publication and dissemination. This dissertation focuses on the first three years. The project brought together collaborators from three institutions in an urban area of the Pacific Northwest, with support from the partner school district. These partners included: secondary teachers and administrators from a public school, STEM Academy[2]; staff from Tech Foundation, a STEM-focused educational non-profit organization; and a research team of learning scientists from a large research university. In addition, disciplinary STEM experts also joined for particular CSP activities. The grant for the CSP was co-managed by principal investigators from the university and Tech Foundation. Two members of the research team had engaged in previous research and education projects with STEM Academy and Tech Foundation, representing a total of four years of prior partner work.

A major focus of the project was to develop computationally-rich secondary science curriculum units that were guided by the *Framework for K-12 Science & Engineering Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013). The Computational Science Project was grounded in a cultural and ecological theoretical framework of human learning and employed a design-based research (DBR) model to guide the development of practices and tools for the co-design team (Computational Science Project, 2015). Research questions for the project centered on teachers' professional learning and disciplinary experts' learning through engagement in co-design, and students' computational learning through participation in the enacted curriculum units (Computational Science Project, 2015).

The CSP aimed to engage interdisciplinary collaborators to co-design science curriculum materials in order to broaden participation in science learning through the integration of computational thinking (CT) practices (e.g., Weintrop et al., 2016), computational tools, complex

[2] All institutional names are pseudonyms.

systems phenomena (e.g., Jacobson & Wilensky, 2006; Yoon, Goh, & Park, 2017; Weintrop et al., 2015), and project-based learning (PBL) (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2005). Computational inquiry, also called computational thinking, is taken here to involve "solving problems using techniques from computing" (Sharples et al., 2015). Computational inquiry has been described by many researchers (e.g., Jacobson & Wilensky, 2006; Sharples et al., 2015; Weintrop et al., 2016) as an important priority for STEM education and is included as one of eight core science and engineering practices in the *Framework for K-12 Science & Engineering Education* (National Research Council, 2012) and the *NGSS* (NGSS Lead States, 2013). As Weintrop and his colleagues (2015) asserted, integrating computational inquiry practices and tools into science instruction "gives learners a more realistic view of what these fields are, better prepares students for pursuing careers in these disciplines, and helps equip students to be more savvy STEM citizens in the future" (p. 128). The inclusion of computational inquiry, computational tools, and complex systems phenomena into the science curriculum is an equity strategy for engaging *all* students in ambitious science learning about current, authentic, real world phenomena (Jacobson & Wilensky, 2006; Yoon, Goh, & Park, 2017; Weintrop et al., 2015). The Computational Science Project, including curriculum design activities, were grounded in these stances around reform-oriented curricula, equitable science instruction, project-based learning, and the integration of computational thinking practices, computational tools, and complex systems phenomena. Ultimately, the CSP resulted in the design and enactment of one chemistry unit and two biology units.

Spheres of Activity

Similar to the work of Severance, Leary, and Johnson (2014) who used the terminology of "multi-tiered structures", we frame the Computational Science Project design-RPP as a *multi-*

sphered structure consisting of interconnected spheres of activity, including the relationships, collaborations, and opportunities for joint work that emerged through the partnership, as well as the boundaries that emerged between members and institutions. Within the space of this design-based RPP, we identified three major spheres that organized partnership activities: the Inter-Institutional Sphere, the Institutional Sphere, and the Intra-Institutional Sphere (see *Figure 1*).

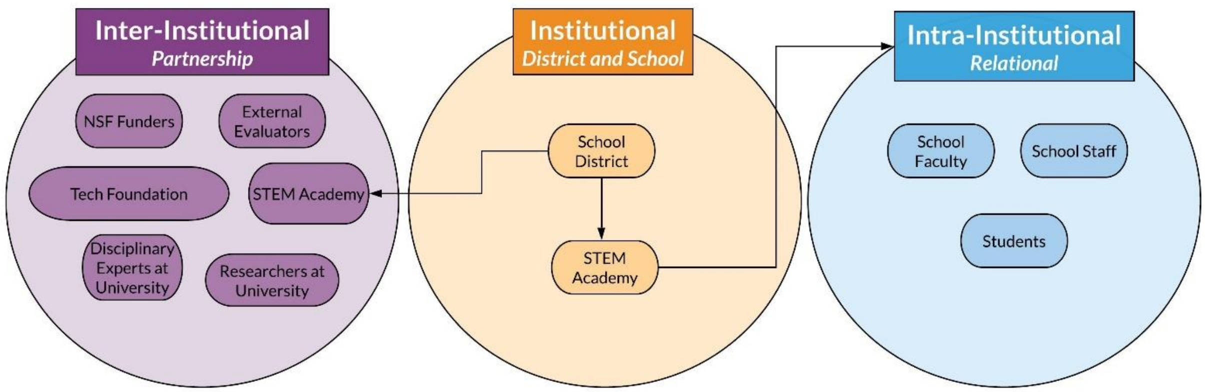

Figure 1. The CSP was conceptualized as a multi-sphered partnership, with the three spheres representing the partnership level, the district and school level, and the relational level within the school building.

The Inter-Institutional Sphere represents the *partnership level*. The Inter-Institutional Sphere included high-level external influencers such as the grant funder as well as the vision and direction of project leaders and researchers. Within the Inter-Institutional Sphere, participants were engaged in forming and maintaining the partnerships of the RPP, providing funding and oversight, and conducting research activities. This sphere consisted of two co-Principal Investigators, the STEM Academy administrator, leadership staff from the STEM Foundation, a small team of educational researchers, several scientists, and the external evaluators for the project. This sphere was influenced by funding priorities and educational policies and initiatives at the national level and the vision of the co-PIs; together, this drove the project goals for the design of NGSS aligned curricula that integrated computational inquiry. As shown in *Figure 2*, some members of the Inter-Institutional Sphere served on the curriculum design team.

The Institutional Sphere represented the *school and district level*, the key partners for curriculum design and enactment work. Activities within this sphere were guided by school district policies and initiatives as well as the school's own structure and culture. District influences that developed over the course of the project included a NGSS implementation initiative, the push for a common district-wide science curriculum, the mandate to integrate earth and space science content into existing secondary science courses, and the district-wide use of standards-based grading. School influences and constraints included staff turnover, a STEM-focused curriculum, course looping, and quarterly interdisciplinary project based learning exhibitions including an annual event highlighting individualized research projects. In addition, in Year Two the school was preparing for a merger with another school that would launch in Year Three, causing many significant challenges related to this growth and change.

The Intra-Institutional Sphere was nested within the Institutional Sphere and represented the interpersonal relationships and expertise within the school building. This sphere included the activities within the school and its classrooms, and relationships among its teachers and students. This sphere consists of the activities of collaborative planning by the school faculty and the activities of teaching and learning in individual classrooms. In the CSP, co-design work was influenced by the perspectives of: grade-level teams across science, humanities, and mathematics; science teachers across middle and high school grade levels; a project manager/instructional coach; and three key teachers. The project was influenced in turn by these teachers' individual classroom practice and their forms of expertise. These teachers served as members of the curriculum design team in different capacities during the design of the three curriculum units.

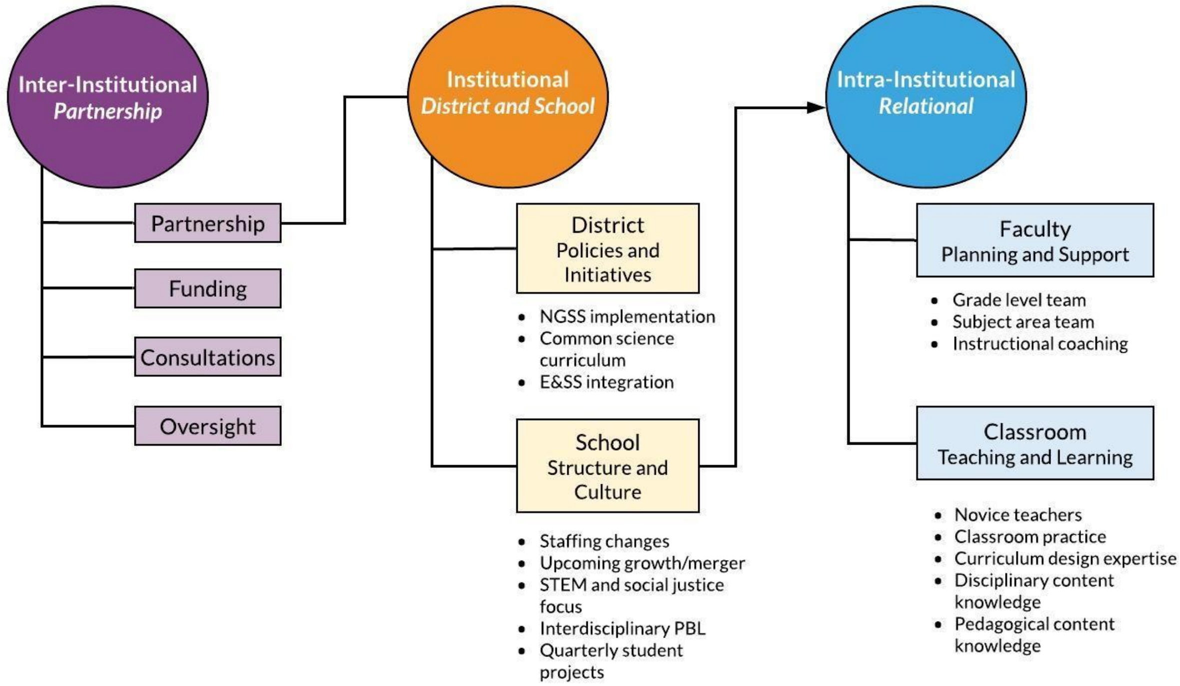

Figure 2. Each sphere of the partnership influenced co-design work. Each of the institutions involved in the CSP exerted different influences, pressures, and constraints on the project. This resulted in design criteria that was multiple, complex, shifting, and at times, in conflict with the project's overall goals.

Participants

The participants in the Computational Science Project partnership that are featured in the empirical studies that make up this dissertation include three science teachers, the project manager/instructional coach, and the research team. Throughout the four years of the CSP, other participants included additional teachers, students, and project manager/instructional coaches. *Table 1* provides an overview of these participants, their roles in the project, their backgrounds, and in which dissertation chapter they are featured. I am included in this table as Researcher 3.

Table 1. Participants in the Empirical Chapters of this Dissertation.

Home Institution	Role Category	Name	Role in CSP	Background**	Chapter of Dissertation
STEM Academy & Tech Foundation*	Science Teacher & Project Manager/ Instructional Coach	Ms. Cruz	Core collaborator; teacher-designer; boundary spanner	Science teacher (five years of experience) with background in chemistry. Master's degree.	Chapters Three and Four Feature case study in Chapter Three
STEM Academy	Science Teacher	Ms. Eider	Teacher-designer for chemistry unit	Second year science and math teacher with background in geosciences. Master's degree.	Chapter Four
	Science Teacher	Mr. Sherman	Teacher-designer for chemistry unit	First year science and math teacher with background in environmental science, chemistry, and biology. Master's degree.	Chapter Four
STEM Academy & Cascade STEM School	Science Teacher	Ms. Ly	Teacher-designer for biology units	First year teacher with background in biochemistry and biophysiology. Teach for America corps member.	Chapters Three and Four Feature case study in Chapter Four
University	Researcher	Researcher 1	PI and CSP Director	Learning sciences faculty.	Chapter Five
		Researcher 2	Researcher	Learning sciences post-doctoral fellow; ecologist; science teacher	Chapter Five
		Researcher 3	Researcher	Learning sciences graduate student; curriculum designer	Chapter Five
		Researcher 4	Researcher	Learning sciences graduate student;	Chapter Five

				evolutionary biologist	
		Researcher 5	Researcher	Learning sciences graduate student; marine biologist; science teacher	Chapter Five

*Note that Ms. Cruz transitioned through multiple positions, home institutions, and roles during her participation in the CSP.

**Note that teaching experience is reported at the time of the formation of CSP in Year One of the project, with the exception of Ms. Ly who began teaching in Year Two of the project.

Three science teachers became key teacher-designers through three years of collaborative curriculum design and enactment work. The two STEM Academy chemistry teachers who co-designed and enacted the chemistry unit in Years One and Two were Ms. Eider[3], a second year teacher, and Mr. Sherman, a first year teacher at the time. The biology teacher who co-designed and enacted the biology units in Year Three was Ms. Ly, a Teach for America corps member. In Year Two of the project, she was a first year science teacher at STEM Academy who also enacted the CSP chemistry unit, however her enactment was not studied by the research team. In Year Three, Ms. Ly was a second year teacher who participated in the co-design of the two biology units and their enactment at Cascade STEM School. This was her first time teaching a biology course. Ms. Ly is featured in a case study in Chapter Four.

In Years Two and Three, Ms. Cruz was the project manager/instructional coach for Tech Foundation and a core member of the CSP team. The year prior, Ms. Cruz had been a science teacher at STEM Academy and participated in co-design sessions for the chemistry unit. At the time she joined the CSP in Year One, Ms. Cruz was in her fifth year as a science teacher. Within the CSP, Ms. Cruz engaged in partnership activities across all three years of the project. She is

[3] All individual names are pseudonyms.

featured in a case study in Chapter Three, in which her coaching and co-teaching practices with Ms. Ly during a biology unit enactment are described.

The members of the CSP research team were also co-participants in this research, as they assumed multiple roles including project coordinators, curriculum designers, and researchers. Throughout the empirical chapters, this dissertation research reports on researcher learning through the CSP experience. The research team consisted of five members, all trained as learning sciences: (a) the CSP director and principal investigator of the CSP grant who was a learning sciences faculty member at the university; (b) three graduate research assistants who were doctoral students, including myself, with backgrounds in evolutionary biology, marine biology, curriculum design, and science teaching; and (c) a post-doctoral research fellow with a background as a science teacher, ecologist, and educational researcher.

The Setting: STEM Academy & Cascade STEM School

STEM Academy was a small, STEM-focused, public neighborhood school serving students in grades six through twelve in a suburban area of the Pacific Northwest. At the time, STEM Academy was reported to be located in one of the most diverse school districts in the state, based on the racial and ethnic demographics of its students. In an unorthodox model, this public school was co-managed by the school district and the non-profit Tech Foundation, with the school providing the context for the foundation to develop its model of school transformation. At the beginning of the CSP's formation, STEM Academy was in its eighth year of operation. STEM Academy had been recognized with state and national awards as being a school of distinction known for its focus on supporting students' development of STEM literacy, twenty-first century skills, and college and career-readiness. The school was also known for its success in serving a culturally, linguistically, and financially diverse student population, in which one hundred percent of students who graduated on-time were accepted into college. According to school documents, STEM Academy's philosophy of equitable education included "having the conviction that every student is capable of learning and being successful" which also related to the long-term mission of Tech Foundation.

STEM Academy was known for its use of project-based learning (PBL) pedagogies (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2005), which includes engaging students in extended, interdisciplinary projects in order to develop their STEM literacy. According to school documents, STEM Academy defined STEM literacy as "the ability to understand and apply concepts and content from STEM, humanities, and arts" as well as "to apply twenty-first century skills" in order to "improve the social, economic, and environmental conditions of their local and global community". The school's model for STEM education included four concepts: interdisciplinary STEM integration across all programs and subject areas; employing a PBL pedagogical model in which students deeply explore personally-relevant issues through classroom projects and technology; engaging students in authentic intellectual work through these real-world projects; and preparing students to be college and career-ready. To support this model of STEM education, the school offered a one-to-one laptop program, access to select software and technology (e.g., laser printer, 3D printer), and opportunities for students to engage with STEM professionals (i.e., mentorship programs, internship programs, STEM competitions).

In Year Two of the CSP, STEM Academy was on the precipice of a major transition as the academy prepared to merge the following academic year with Cascade School, a larger, under-performing middle school in the same district. As part of the transition, Tech Foundation was invited by the district to bring their school transformation model to the new setting. With this merger, the school would also change from a middle school to one that would serve students in grades six through twelve. The merger changed almost all aspects of STEM Academy, including its physical location, its culture, a large increase in the size of its student body—from 310 students in 2016-2017 to 689 in 2017-2018—and changes to its faculty and administration team. Current school data for the merged Cascade STEM School from 2018-2019 reports over a third of students are Hispanic/Latino, slightly less than a quarter are White, followed by Two or More Races and Black/African American (thirteen percent each). Over two-thirds of students are from low-income families. This transfer of the PBL program to this new school created an ever-shifting, transitional context for the Computational Science Project, and so it became an important aspect of this research.

Timeline of the Computational Science Project

The Computational Science Project launched in October 2015. In this section, I describe the phases of the project over three years, based on the academic year calendar. *Figure 3* features a timeline that provides an overview of major partnership activities and shifts in context.

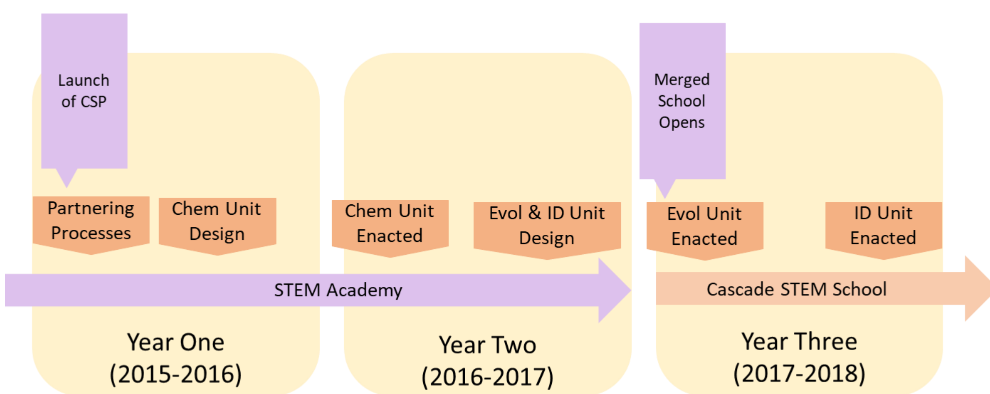

Figure 3. This timeline of the Computational Science Project tracks partnering activities as well as the design and enactment of the chemistry (Chem) unit, biology evolution (Evol) unit, and the biology infectious diseases (ID) unit. Years are represented using the academic calendar of September through August.

Year One (2015-2016): Project launch & chemistry unit design. The first year of the Computational Science Project was the partnering, launch, and design phase. The focus was on developing partnering processes, forming relationships with teachers and administrators, developing our shared understanding of computational inquiry, and engaging in initial collaborative design work. The goal was to design, enact, and revise a computationally-rich science unit. The co-design team shifted throughout the first year, but consisted mostly of a small group of middle and high school science teachers from STEM Academy, learning scientists from the university, and on occasion, disciplinary experts from the university. Three high school science teachers (Ms. Cruz, Ms. Eider, and Mr. Sherman) were positioned by their principal to be the key teacher-designers in this effort, with the other teachers playing a supporting role. Over time, Ms. Eider emerged as the lead teacher-designer in this effort.

Thirteen in-person design sessions were held, taking place at the school or at the university campus. The goal was to collaboratively author the unit in real-time together. The focus of earth's early formation was chosen due to the school district's mandate that chemistry, physics, and biology courses integrate earth and space sciences content. The use of software tools such as Google Docs and Google Sheets became a routine for engaging in this collaborative work. Ultimately, a high school chemistry unit, *Chemistry of Early Earth's History*, was drafted and prepared for enactment in the fall. As written, the curriculum was designed for four to six weeks of instruction. It should be pointed out that the partner teachers had a strong preference for designing flexible curriculum materials that offered a menu of options, rather than a more formalized and detailed instructional plan. Therefore the curriculum materials that were designed for the chemistry unit followed this approach. These co-design sessions were an important part of the CSP's partnering process in which the project's shared vision, curriculum design approach, research agenda, and collaborative practices began to develop. At the end of the school year, one of the science teacher collaborators, Ms. Cruz, resigned from her position.

Year Two (2016-2017): Chemistry unit enactment & biology units design. Beginning in Year Two, one of the science teachers who had collaborated on the design of the chemistry unit, Ms. Cruz, was hired as a project manager/instructional coach by Tech Foundation to work directly on the Computational Science Project. This position included two roles. First, in the project manager role, Ms. Cruz was to work directly on the Computational Science Project as a representative of Tech Foundation. In this role, she began attending weekly CSP partnership planning meetings with the research team held on the university campus. Her second role was an instructional coach. In this role, she spent time at STEM Academy coaching and supporting the science and math teachers at the school. In this way, Ms. Cruz had her foot in three partner institutions that made up the CSP: the university, the foundation, and the school.

The second year of the CSP was focused on the enactment of the chemistry unit in the fall, followed by the design of two biology units. The chemistry unit was enacted by three teachers, two of whom were key members of the design team (Ms. Eider and Mr. Sherman), and the third (Ms. Ly) who was a first year teacher at the time working with Ms. Eider. The unit enactment occurred over eleven weeks of instruction in the three classrooms. Ms. Cruz supported this enactment in her new role as project manager/instructional coach. Data collection focused on the enactment of the unit in Ms. Eider's classroom.

Due to the teachers' preference for a loose plan with multiple instructional options rather than a detailed curriculum, the chemistry unit enactment required each teacher to engage in significant adaptation and night-before planning during instruction. This approach resulted in a unit that as enacted was not as computationally rich as the researchers had hoped for. It has not been determined if the initial chemistry unit will be revised and prepared for dissemination. This result, as well as developing an understanding of the types of supports needed by novice teachers engaged in this type of co-design and enactment work led the research team to pivot in their approach, implementing a different co-design model in Year Two that was more researcher-led and involved more intense classroom support during enactment.

At this point, attention shifted to the design of additional science curriculum units which would focus on global climate change. An ad hoc climate science working group was formed with disciplinary experts, researchers, STEM Academy teachers and staff members, and consulting teachers from another school district to inform the initial ideas for the units (for a detailed description of this process, see Chapter Five). Then, rather than engaging in design sessions with an interdisciplinary team as was the model in Year One, two CSP graduate researchers with relevant science backgrounds took the lead in drafting two high school biology units, both of which integrated earth and space sciences content as mandated by the school district, with a specific focus on biological impacts of climate change. The first unit, *Sea Star Wasting Disease: Impacts of Climate Change on Evolution & Diversity*, was an extended biology unit focused on evolution and genetics. The curriculum was written for six to eight weeks of instruction. The second unit, *Climate Change & Infectious Disease Outbreaks*, was a mini biology unit focused on infectious diseases. The unit was designed for one to two weeks of instruction. During the design of these units, the researchers consulted with Ms. Ly, who had been identified by her administrator as the key teacher collaborator moving forward. With input from this teacher, two biology units were prepared for enactment in her classroom for the following academic year.

Simultaneously, STEM Academy was preparing for the school merger, which would take place in the fall. There was a significant turnover in faculty and administrative staff at the school, including Ms. Eider, the chemistry teacher whose enactment had been studied. Ms. Eider took a temporary leave from her teaching position about one month after the conclusion of the chemistry unit enactment, stating health reasons. She later resigned from her position and did not return.

Year Three (2017-2018): School merger & biology units enactment. In the fall of the third year of the project, the merged Cascade STEM School was launched. Ms. Ly was now in her second year of teaching, and Ms. Cruz was in her second year of her Project Manager/Instructional Coach position with Tech Foundation. Ms. Ly enacted the extended evolution unit (Fall 2017) and the infectious diseases mini-unit (Spring 2018), each with two sections of ninth grade biology students. During enactment of the evolution unit, Ms. Ly received significant support from researchers and Ms. Cruz. In particular, Ms. Cruz developed a co-planning, co-teaching, debriefing practice with Ms. Ly, which included Ms. Cruz co-teaching during one of her class periods. Additionally, Ms. Cruz and I met with Ms. Ly, in person or virtually, for almost-daily debrief sessions to reflect on each day's instruction and plan for the next day. Ms. Cruz also continued to attend weekly CSP partnership planning meetings. Researchers made class observations several times a week during the fall enactment of the evolution unit for data collection purposes. During the enactment of the infectious disease unit in the spring, data collection and instructional support activities were less intensive as they had been in the fall.

Extensive data collection during enactment of the evolution unit informed revisions to the unit. A template system was designed by the researchers as they worked to create a more complete and formal version of the unit. In the spring, a biology teacher at a different school in another state enacted the computationally-focused project work component of the evolution unit, providing additional feedback to inform the unit revision and templates. Both the evolution and infectious disease units have been revised and prepared for publication, with the goal of wide dissemination.

Models of Collaborative Curriculum Design Across the CSP

Curriculum design activities in the CSP were approached through co-design. While the design team changed in size and composition over the three years of the CSP, it consistently pulled members from institutions that made up the spheres of the partnership. The design team engaged participants from the Intra-Institutional and Inter-Institutional Spheres, with influence from the Institutional Sphere, as shown in *Figure 4*. The design team consisted of representatives from the university (researchers and the CSP director) and Tech Foundation (project manager/instructional coach Ms. Cruz) of the Inter-Institutional Sphere, as well as representatives from the school teaching staff (key teacher-designers Ms. Cruz when she was still a teacher, Ms. Eider, Mr. Sherman, and Ms. Ly) from the Intra-Institutional Sphere of the partnership. At different times in the design process, the design team also collaborated with university scientists, middle school science teachers, and grade level teaching partners from humanities and mathematics. In addition, during our co-design work together, we acknowledged and accommodated the influences of the school and district from the Institutional Sphere, which at times caused the team to make major shifts to design work due to the constraints of district policies and school structures.

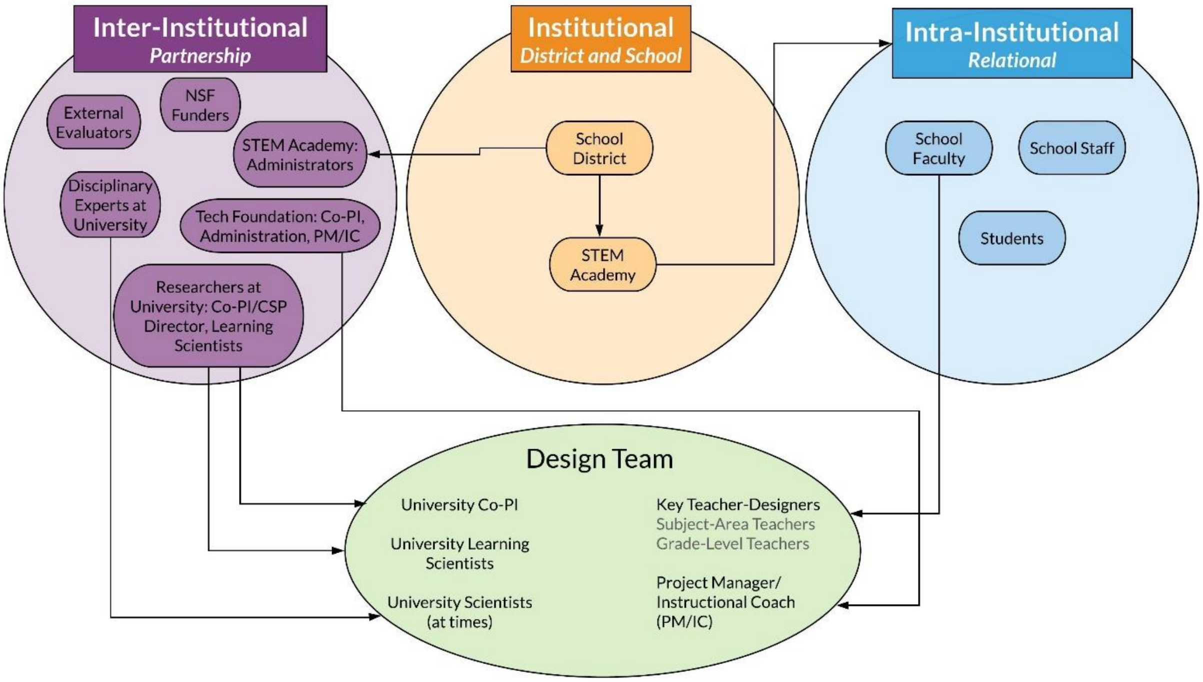

Figure 4. The curriculum design team within the CSP partnership engaged participants from the Inter-Institutional and Intra-Institutional Spheres, with influence from the Institutional Sphere.

Two different models for collaborative curriculum design were developed, employed, and tested during the lifespan of the CSP. As a new design collaborative, Co-design Model #1 was developed and implemented during Year One of the CSP for the design of the chemistry unit. Based on the experience of co-design and enactment with early-career science teachers, the research team pivoted in their approach, employing Co-design Model #2 during Year Two of the CSP for the design of the two biology units. These two models are described below.

A collaborative design table approach: Co-design model #1. The co-design approach for the chemistry unit taken in Years One and Two consisted of an interdisciplinary design team with membership from the university, Tech Foundation, and STEM Academy that met for thirteen design sessions over an eight-month period. Though the membership of the design team changed over time, a partnership formed with two key teacher-designers, Ms. Eider and Mr.

Sherman. Activity structures for this model of co-design included: leadership meetings, partnership formation meetings, planning meetings, shared informal professional learning, formal professional development, and thirteen in-person co-design sessions (some which included disciplinary experts).

This approach to design resulted in a skeletal unit plan consisting of multiple instructional choices, at the request of the partner teachers due to their own preferences for lesson planning. Ms. Eider and Mr. Sherman then enacted the unit in their classrooms, relying extensively on night-before-planning and local adaptation (Barab & Luehmann, 2003). A local versus global tension also emerged between a local focus for what worked best for STEM Academy's students and teachers and what would be accessible to wider contexts upon publication. Therefore it is uncertain if the unit will be revised and published for wide dissemination. Chapter Four shares findings related to Ms. Ly and Mr. Sherman's professional learning through the experience of designing and enacting the curriculum unit. Design tensions emerged in this work that stemmed from engaging novice teachers in co-design and the challenges of supporting the unit's enactment in the classroom and teachers' varying forms of developing expertise. Therefore we pivoted and moved to a different approach toward co-design for the two biology units.

A researcher-led design approach: Co-design Model #2. The co-design approach for the biology units taken in Year Two positioned two CSP researchers—learning sciences graduate students with relevant science backgrounds—as lead authors of the units, in collaboration and consultation with the partner teacher, Ms. Ly. This resulted in a two units fleshed out in detail, including supporting student and teacher documents, an extended team project, and summative assessments. Activity structures implemented with this approach to co-design included (see

Chapter Five): leadership meetings; weekly planning meetings; shared informal professional learning; the formation of an inter-professional and cross-institutional ad-hoc Climate Science Working Group that met for three sessions; collaborative design sessions with two consulting biology teachers; co-design with Ms. Ly; and eliciting scientists' feedback while selecting the anchoring phenomenon and during unit design and enactment. During unit enactment, activity structures included: co-planning, co-teaching, and daily reflective debriefs. On-going research activities, such as interviews, allowed additional opportunities for reflection.

During the enactment, Ms. Ly was supported through: a) co-teaching and co-planning with an instructional coach, Ms. Cruz; b) almost daily debrief sessions with myself and/or Ms. Cruz; c) support via email by the research team; and d) classroom support from researchers when requested (e.g., helping student groups during a dissection lab, acting as chaperones during a field trip, serving as extra adults in the room). During enactment, adaptation choices and the realities of authentic classrooms surfaced pedagogical, instructional, and technical opportunities and challenges. Boundary practices emerged between Ms. Ly, Ms. Cruz, and the research team to respond to opportunities and to negotiate challenges, as featured in Chapter Three. The curriculum units as enacted were computationally-rich as defined by the researcher team's goals and vision. The units are currently being revised and published for wide dissemination. The result of these two models of co-design was the design and enactment of three high school science units that integrated computational practices and earth and space sciences content. Details are provided about each of these units in *Appendix B*.

Design Tensions Perspective

During Year Two of the CSP, I introduced Deborah Tatar's (2007) design tensions paradigm to the CSP research team as a way to conceptualize our design processes. Tatar (2007) developed her design tensions framework within the field of human-computer interaction (HCI) as a way to understand the process of adapting SimCalc, a desktop system for mathematics instruction, to become NetCalc, a system of wirelessly-connected handheld computers. Tatar frames project tensions as the choice between two concrete design option, as choices between *this vs. that.* I was inspired by the work of Severance, Leary, and Johnson (2014), who applied this conceptual framework to the field of learning sciences as a way to guide their analysis of design tensions within a three-tiered design-based RPP focused on the design of EdTrex, a digital platform used for customizing mathematics curriculum (see also Johnson, Severance, Penuel, & Leary, 2016).

Tatar's (2007) design tensions framework provides four levels of concern:

1. **Vision:** The vision or potential for the project, and how what *is* differs from what *ought to be.*
2. **Approach:** The intended implementation of the vision.
3. **Project Tensions:** The value-laden design decisions that occur in the project during times of conflict and which are solved through a process of negotiation. Tensions often arise from competition for limited resources and a need for balance.
4. **"As Created" Situations:** The potential outcomes or consequences of the implemented design choices.

Tatar's (2007) design tensions paradigm became important for understanding the tensions and opportunities that guided the design choices in our co-design process, in which the complex process of design is conceptualized "not as problem solving but as goal balancing" (p.

415), and through which design tensions are resolved through compromise. Indeed, tension is part of design itself, for "design exists because of the tension between what *is* and what *ought to be*" (Tatar, 2007, p. 415). We adapted the design tensions framework to consider the tensions that occurred not just in the design of a particular project element, but rather in the routines, practices, and tools that supported the work of the design team within the RPP. In this way, the framework provided an analytic lens for examining the ways that the members of a design-RPP negotiated design decisions. This use of the design tensions framework helped us to identify tensions and boundaries in the joint work of the CSP partners; these tensions and boundaries served as the inspiration for each of the three empirical chapters that make up this dissertation. Here, I summarize the four areas of concern that make up this framework and explain how they relate to the CSP.

Project vision. The vision of a project is described by Tatar (2007) as the potential for that project, with a focus on how what *is* differs from what *ought to be*. The original vision for the CSP, the *"what ought to be"*, was formed by the project leaders within the Inter-Institutional Sphere. This vision was then influenced by policies and structures from the district and school in the Institutional Sphere, which caused the members of the design team to negotiate a revised vision, an amended *"what ought to be"*, and recognize these pivot points as design opportunities. This process of developing a shared vision for the project and negotiating alignment around a revised vision necessitated that members of the design team navigate the institutional boundaries of these two spheres.

Early on, the participants in our design team found alignment around a shared vision of *"what is"*. At its inception, the project was focused on the co-design of project-based, NGSS-aligned, equity-oriented secondary STEM curricula that integrated computational inquiry, along with the broader goal of developing tools, practices, and strategies for collaborative curriculum design. STEM Academy and Tech Foundation voiced a strong commitment to educational equity and serving culturally and linguistically diverse students. The school was in the process of adapting all science courses to align with NGSS. This was in line with the researchers' collective vision of "what is" in terms of equitable science learning.

However, the project vision shifted at several points due to influences from the Institutional Sphere, resulting in a revised vision of what *ought to be*. For example, during the initial design process focused on a climate change unit for biology classes, the project team had to shift the content focus to chemistry, due to changing teaching assignments for the two key co-design teachers. Also, the design team learned that in an effort to align with NGSS, the district was implementing the California NGSS model for integrating earth and space sciences content. Therefore, the district required STEM Academy, which did not offer an earth and space sciences course, to incorporate this content into existing biology, physics, and chemistry courses. The school was committed to using project-based approaches to learning and had an existing structure that involved students in interdisciplinary projects across their science, humanities, and math courses that culminated in three project exhibitions per academic year. The compressed timeline created by these two elements of the Institutional Sphere added new criteria to the design of the curriculum. As each of these shifts in vision occurred, the design team negotiated their meaning and at times made major pivots in the design process. This revised vision of what *ought to be* included the idea that high school science curricula should integrate computational inquiry and earth and space science content, should deeply align to NGSS and phenomenon-based instruction, should be rooted in equitable classroom instruction strategies, should provide opportunities for highlighting student interest and engagement, and should fit well with a PBL approach to instruction. However, as will be surfaced in Chapters Three and Four, not all of the CSP partners had a similar idea of how to operationalize the concepts that made up our shared vision, or how to approach them during classroom instruction.

Project approach. The project approach is the intended implementation of the vision, "an attempt to bring goals and values (what *ought to be*) into relationship with pre-existing reality (what *is*) in a way that leads to action" (Tatar, 2007, p. 418). The overall approach for the project was crafted by the Principal Investigators, supported with funding from the National Science Foundation, and implemented by the educational researchers who managed the project. At both the leadership level of the Inter-Institutional Sphere and at the level of the design team, participants appeared to have alignment around major project drivers. For example, the team valued co-design within a research-practice partnership as an effective model for teachers' professional learning and a rich context for the design of reform-based science curriculum. The team was in agreement that a major focus of curriculum design would be the integration of computational inquiry. Likewise, the team was motivated to develop curriculum materials with deep alignment to the NGSS and the underlying *Framework for K-12 Science Education* (National Research Council, 2012). In addition, designing for student engagement was an important focus for all members of the design team, although it turned out that members operationalized this concept in different ways. The core members of the design team developed collegial relationships (Barth, 2006) and leveraged each other's expertise during joint work.

Project tensions. Project tensions are the value-laden decisions, the "places in the project that (a) directly or indirectly fall within the designers' scope of influence but (b) where means, ways, and values come into conflict" (Tatar, 2007, p. 418). Within an RPP, tensions are multiple, complex, located in the boundaries between the institutions that make up the partnership, and emerge throughout the process of co-design work. Therefore, partners need to make systematic choices throughout the process. These choices may involve multiple people across spheres, who may have conflicting views. We encountered and navigated through many project tensions during our co-design work. Three major project tensions are further explored in each of my empirical chapters.

“As created” situations. “As created” situations are the “situations or dilemmas represented by the new reality and the consequences that flow from that reality” (Tatar, 2007, p. 419). They can be thought of as “another set of considerations raised by the pragmatic accomplishment of the project” (Tatar, 2007, p. 444). For example, an “as created” situation in the CSP was the multiple design criteria involved in this project. When the CSP was first conceived, it was envisioned as a design-RPP that brought together interdisciplinary collaborators to co-design curricula that aimed to broaden participation in science learning with the support of computational inquiry and tools. Later, due to pressures and influences from the Institutional Sphere we added additional district and school-specific criteria. These additional criteria added to the complexity of our design challenge, as we negotiated these complex and at times, competing goals. These specific criteria were unique to the CSP partnership, and moreover, to our partnership with STEM Academy, Cascade STEM School, and the partner district, but the broader tensions that emerged are likely relevant to the complexities involved in other design-RPPs.

Organization of this Dissertation

This dissertation consists of a conceptual synthesis of relevant literature followed by three empirical chapters. Three project tensions served as inspiration for the studies I designed for each of these empirical chapters. First, at the level of the partnership, Chapter Three grapples with the tension that occurred across the spheres of the partnership of spanning institutional, sociocultural, and professional boundaries within the CSP in order to carry out our joint work. Second, at the level of the design team, Chapter Four examines the tension of supporting co-design practices and curriculum enactment when the key teacher-designers are novices still developing their own classroom practices. Finally, at the level of the designed curriculum itself, Chapter Five describes how the CSP partners developed selection criteria and engaged in selection processes in response to the design tension of selecting scientific phenomena to anchor units of instruction. Each chapter is summarized below.

Chapter Two presents a conceptual synthesis of the literature that is relevant for this dissertation and that supports the three empirical chapters. “Partnership-based Approaches to the Collaborative Design of K-12 Science & Engineering Curricula: A Conceptual Synthesis of the Literature” is organized into three sections. First, I present literature focused on collaborative design, or co-design, as an approach to the design of curriculum materials. I examine different models of collaborative curriculum design and teacher professional learning, examine the historical foundations of partnerships in science education, and summarize literature on research-practice partnership. Second, I present literature specific to design-focused research-practice partnerships in education, including offering theoretical lenses that can be employed for understanding co-design processes and illustrating how design-based research has been commonly used as a methodology for the study of co-design practices within design-RPPs. Finally, I summarize literature that shows how teachers might engage in professional learning through engagement in co-design initiatives by examining the curriculum-teacher relationship, and what we know about how teachers learn through their use of educative curriculum materials, their participation in the design of curriculum materials, and their involvement in the enactment and local adaptation of curriculum materials. I present four conceptual frameworks that have been proposed in the literature for studying teacher learning through curriculum design. I note that there is an absence of conceptual frameworks specific to teacher learning through co-design in design-RPP contexts. Therefore these models, while not specific to this context, are a potential starting place for developing new understandings. In this chapter, I argue that there is much that the research community has yet to investigate regarding science teachers' learning, collaborative curriculum design practices, and participation in design-RPPs. In particular, more research is needed to understand how co-design initiatives may support or constrain professional learning for early-career teachers. I argue that richly descriptive design narratives of collaborative work are needed to share details about complex forms of cross-practice workplace learning and collaboration. My empirical chapters seek to make this contribution to the literature base.

Chapter Three presents a qualitative, micro-ethnographic case study of Ms. Cruz, a former science teacher who was assigned and who assumed multiple roles within the CSP partnership. "Role Fluidity Across (Im)Permeable Boundaries of Partnership: A Case Study of a Boundary Spanner within a Research-Practice Partnership" shares the ways that Ms. Cruz attempted to facilitate joint work across the boundaries of the CSP partner institutions, while also sharing how she moved through various roles, articulated work processes, and encountered boundaries that were more and less permeable to her. Through an analysis of Ms. Cruz's experiences across three years of the partnership, I asked: *What roles did a person positioned as a boundary spanner take on in a design-based RPP, and who benefited from her participation? How did she cross the boundaries of the respective institutions in the partnership and in what ways was she constrained in this work*? Two theoretical lenses are employed to understand Ms. Cruz's experiences; the relational turn in CHAT focuses on understanding inter-professional and cross-practice collaborations at work (Edwards, 2005, 2011, 2012) while a social practice lens is useful for thinking about a boundary spanner as a person-in-practice (Dreier, 2016) while examining her professional learning trajectory, identity development, and change through her participation in the project, across roles and over time, as well as the roles made available to her through porous categories of work. Key data included interviews, observations, and artifacts. This case study sought to understand what roles Ms. Cruz took on, and who benefited from her participation. This study also sought to understand how Ms. Cruz attempted to cross the boundaries of the respective institutions in the CSP partnership, in what ways she was supported or constrained in this work, and its impact to the CSP and its goals.

Chapter Four presents a qualitative case study of Ms. Ly's professional learning pathways as she engaged in co-designing, adapting, and teaching computationally rich biology curricula through participation in the CSP. "Professional Learning of an Early-Career Science Teacher through Co-Design in a Research-Practice Partnership" investigates how participation in a design-RPP might may serve as an alternative, practice-oriented approach to teacher professional development that is collaborative, social, sustained, and networked, while also examining the challenges to this work with novice teachers who are still developing their own classroom practices. With this study, I sought to understand, *How did the involvement of an early-career science teacher in co-design, local adaptation, and reflective enactment of curricula benefit and challenge her professional learning, development of various forms of expertise, and professional practice?* and *Should early-career teachers be asked to take on critical partner roles in design-RPP endeavors?* While this chapter features a case study of Ms. Ly, a Teach for America corps member who participated in the CSP as a chemistry and biology teacher, it also includes data from one other STEM Academy early-career science teacher, Mr.

Sherman, who was involved in the co-design and enactment of the chemistry unit, to expand the findings across cases. Data was collected using ethnographic field methods. Key data included semistructured interviews and supporting data included classroom observations, debrief sessions, and entries in a debrief journal. In this chapter, I share design knowledge that surfaced through interviews with two key teacher-designers involved in the CSP.

Chapter Five presents a qualitative design narrative that features a specific design tension that arose during the co-design of the biology evolution unit. "Navigating Tensions in Co-design through Knotworking: Selecting Contemporary Scientific Phenomena for High School Biology Curriculum" shares the CSP design team's experiences with developing criteria for selecting an anchoring phenomenon for a high school biology curriculum unit that met the needs of CSP partners. With this chapter, I sought to understand: *What processes and criteria for phenomenon selection should be used for the design of high school biology curricula? In particular, what selection criteria and processes of selection would support the design of curricula focused on a contemporary, locally-relevant, and computationally-rich scientific phenomenon that engages students in the socio-scientific issues of global climate change and evolution?* By detailing the processes of knotworking (Engeström, 2008) and other activity structures that the members of the CSP engaged in, I show in this chapter how the team negotiated the design tension of selecting scientific phenomena for curriculum design and instruction by engaging collaborators with specific and diverse forms of expertise. Key data included ethnographic field notes and analytical memos from work group meetings and design sessions, artifacts, and practical measure surveys. In this chapter, I share four design principles relevant to co-design approaches to phenomenon-driven curriculum materials.

Chapter Six provides the conclusion to this dissertation. In this chapter, I present a new conceptual framework for understanding how professionals learn through collaborative curriculum design activities within the structure of design-RPPs. The Framework for Professional Learning through Design in Partnership provides a new conceptual and analytical tool for researchers engaged in these types of partnerships. I then summarize the major findings from the three empirical chapters, sharing an analytical chain for each chapter using the Framework for Professional Learning through Design in Partnership. I also share design knowledge that may be relevant to other researchers engaged in design-focused research-practice partnerships or those who are developing partnering processes. This design knowledge in particular may be relevant for those engaged in collaborative design practices through RPP structures, who are focused on the design of innovative, NGSS-aligned curriculum materials, and those who might be considering engaging early-career science teachers in this complex work.

Analytical Concerns & Limitations

Coburn and Penuel (2016) warned that much of the existing research on the dynamics of partnerships within RPPS focus on first-person accounts of the researchers themselves, which may suffer from hindsight bias and lack the perspective of the other participants in the partnership. These authors push for the inclusion of outside researchers, those not involved as participants in the RPP, to construct a fuller account of all participants and to “study partnerships in real time, thus avoiding bias introduced in retrospective analysis” (Coburn & Penuel, 2016, p. 50). While the CSP research team argues that our insider perspective and our ethnographic approach afforded us an important vantage point for understanding the nuances of the tensions and the resulting outcomes on the co-design process, we also see value in this criticism.

Many RPPs, like the CSP, are university-initiated (Coburn & Penuel, 2016), which positions educational researchers as both insiders and outsiders as they take on multiple roles as the rainmakers, planners of the collaboration, co-participants in project activities, and researchers. The studies in this dissertation by design include the perspectives and experiences of the educational researchers who were tasked with the planning and administration of the project, and who acted as participants-as-observers (Merriam & Tisdell, 2016) in partnership activities and the co-design process, as is seen in the design narrative in Chapter Five. This immersion allowed the researchers to take an ethnographic approach to field work, which "involves both being with other people to see how they respond to events as they happen and experiencing for oneself these events and the circumstances that give rise to them" (Emerson, Fretz, & Shaw, 2011, p. 3). While the researchers on this project recognize that we can write from our own perspective and about what is relevant to us as researchers, we also took care to "reveal the multiple truths" by including the perspectives of others who were involved in the project from both insider and outsider positions (Emerson, Fretz, & Shaw, 2011, p. 4). For example, the case studies in Chapter Three and Four, give voice to the project manager/instructional coach and teacher-designers involved in the partnership by leveraging interview transcripts. We also saw value in including an outsider perspective. Throughout the CSP, we worked closely with a team of external evaluators who examined the process and outcomes of the project. Feedback from these external evaluators at times influenced our partnering processes and design decisions for the project.

As a strategy for ensuring internal validity, when possible, I conducted member checks (Merriam & Tisdell, 2016) with research participants and checked my interpretations and recollections with other members of the research team. I also engaged in triangulation across data types, sources, and perspectives (Merriam & Tisdell, 2016). When developing the case studies and design narrative, during the writing of these chapters I returned to the data to develop thick descriptions (Geertz, 1973; Merriam & Tisdell, 2016) of the unfolding activity.

Researcher Positionality

At the time of this study, I was a doctoral student and employed as a graduate research assistant by the Computational Science Project. I was involved in project planning, project management, co-design, and data collection activities through all four years of the project, sharing responsibilities with two other graduate students, a post-doctoral researcher, and the PI/director.

Data collection activities were coordinated through collaboration between myself and two other graduate researchers. As part of the CSP, I took on the role of an active participant in weekly planning meetings and contributed to our collaborative meeting notes. I was involved in the design of the templates used for curriculum design work, and once the biology evolution unit was authored and piloted in Ms. Ly's classroom, I took the lead on implementing revisions to the curriculum and preparing it for publication and dissemination. During the initial enactment of the chemistry unit and the biology evolution unit, I collected data through classroom observations while also meeting with Ms. Ly for instructional debrief sessions several times a week. I conducted all five of Ms. Cruz's interviews, affording us approximately five and a half hours of in-depth conversations together. I conducted all three interviews of Ms. Ly's interviews, providing us with approximately four hours of conversations together. I also conducted the interviews with the other partner teachers, Ms. Eider (two interviews; approximately two and a half hours total) and Mr. Sherman (two interviews; approximately two hours total). To make classroom observations during the enactment of the chemistry unit in Year Two, I traveled to

STEM Academy, which was located approximately 20 miles from the university. During the enactment of the biology evolution unit in Year Three, I traveled to Cascade STEM School, which was located approximately 30 miles away. I did not personally participate in all of the meetings of the Climate Science Working Group described in Chapter Five due to being on medical leave at that time.

Before either Ms. Cruz or I became involved in the CSP, we knew each other from a different context. As a novice teacher at STEM Academy, Ms. Cruz had participated in a summer research experience at an engineering research center at the university. I was the manager of that program at the time, and over a seven-week period, met with Ms. Cruz and other participating teachers to provide coaching in the design of engineering education curriculum materials. I had also made a visit to Ms. Cruz's classroom at STEM Academy as part of that program to observe her enacting lesson materials she had co-authored. We had already established good rapport prior to the beginning of the Computational Science Project.

My positionality is as a White female, a learning scientist, and a science educator and curriculum designer. I brought to this work two decades of experience in K-12 science and engineering education program management and in particular, expertise in curriculum design. With my lens as a curriculum designer, I was particularly interested in investigating these threads of research within the overall CSP that focused on teacher and researcher learning through engaging in collaborative curriculum design practices. Almost ten years ago, I had an experience as a curriculum design consultant that piqued my interest in co-design. I was hired to lead the design of an interdisciplinary high school curriculum unit focused on global health topics for use in U.S. History, General Chemistry, and Advanced Algebra courses. For this project, we brought together in partnership the following collaborators: global health professionals, a curriculum consultant, an assessment consultant, an external evaluator, and twelve high school teachers. These teachers came from four widely different public schools from different parts of the state—representing urban, suburban, and rural communities. Over three years, we met for in-person design sessions in which we engaged in joint work as we developed collaborative design practices. As a curriculum designer, this experience left me wanting to know more about how to structure and facilitate these kind of collaborative approaches to curriculum design. I wanted to know if curriculum designed through collaboration—in particularly when teachers were brought together with disciplinary experts—resulted in better, more relevant, and adaptable curriculum materials than those sold by commercial publishers. I was curious what forms of expertise and professional learning teachers developed through this work, and how partnerships could be structured to support teacher learning. The Computational Science Project provided the context for me to explore some of these questions through this dissertation research.

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Chapter 2: Partnership-based Approaches to the Collaborative Design of K-12 Science & Engineering Curricula

A Conceptual Synthesis of the Literature

Overview and Purpose

Increasingly, teachers, researchers, disciplinary experts, and others are joining together to design innovative educational interventions in a process known as collaborative design or co-design. Often, co-design is employed as a practice for developing reform-oriented instructional materials, as has been seen with the design of K-12 science and engineering curriculum materials. For example, in science education, policies that focus on the implementation of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) advocate for school leaders to build partnerships and networks to undertake this type of co-design work, drawing on the distributed expertise across such partnerships to fill the void of curriculum materials designed with NGSS (e.g. Severance, Leary, & Johnson, 2014). However, there is much that we do not know about the partnership structures, dynamics, and outcomes of these co-design initiatives, nor their historical, theoretical, and methodological traditions. Moreover, while the research base is extensive on investigations of teacher learning, there is much we do not understand about how teachers learn through engagement in collaborative curriculum design within a partnership. In particular, the research base is underdeveloped on understanding teacher learning within design-focused research-practice partnership structures, and almost non-existent on studies of early-career teacher learning in these settings.

This conceptual literature review explores these topics and surfaces gaps and opportunities for future research by considering collaborative design through partnership broadly. As such, this literature synthesis spans extant literature across many fields of inquiry. A summary is also provided of the diverse theoretical orientations and methodological approaches used by researchers investigating approaches and outcomes from collaborative curriculum design. Where possible, this review will provide examples specific to the design of science education materials. However, in order to explore the topic of co-design through partnership, this review will engage the literature base more broadly.

This chapter is organized into three major sections. Part I introduces co-design as an approach to the design of curriculum materials. Part II focuses on a particular type of partnership context for this work called design-focused research-practice partnerships. Part III investigates the literature base focused on teacher learning through co-design activities within partnership structures. I conclude by surfacing opportunities for future research, including those that are taken up in the three empirical chapters of this dissertation.

Part I: Collaborative Design as an Approach to the Design of Curriculum Materials

In order to understand how high quality subject matter curricula is designed through partnership, in this section I will describe different models for collaborative design from the Netherlands, Japan, and United States. I will then trace the historical foundations for the formation of partnerships within science education, focusing first on university-school partnerships broadly, before focusing on research-practice partnerships in education. I will also trace co-design's roots in participatory design research traditions.

What is Co-Design?

In broad terms, collaborative curriculum design, also known as *co-design*, is the process by which teams work together on the design, adaptation, and enactment of educational interventions. These design teams consist of groups of teachers who may be joined by some combination of administrators, instructional coaches, curriculum specialists, instructional designers, university researchers, disciplinary experts, and other specialists. These design communities bring together professionals with diverse expertise with the mutual goal of creating a designed product in the form of a curriculum artifact (see Voogt et al., 2015), with a focus that may be local (i.e., for use in a particular school or district) or global (i.e., for publication and broad dissemination). Co-design as an approach has also been used to design educational technologies, professional development experiences, and strategies for school or district reform (Severance, Penuel, Sumner, & Leary, 2016).

An overarching assumption of co-design initiatives is that the distributed expertise of the team and the processes of collaboration will lead to the production of quality curriculum materials that upon enactment in the classroom will positively impact student achievement (Coburn & Penuel, 2016) and have positive outcomes for teacher professional learning (Voogt et al., 2011). Studies have found that teacher participation in co-design efforts, especially those that include the enactment of the designed curricula, may: develop specialized forms of teacher knowledge and curriculum design expertise (Huizinga et al., 2014); foster teacher agency (Severance, Penuel, Sumner, & Leary, 2016; Voogt et al., 2015; cf Velthuis, Fisser, & Pieters, 2015); and increase teacher ownership over the curriculum innovations (Binkhorst, Handelzalts, Poortman, & van Joolingen, 2015; Huizinga, Handelzalts, Nieveen, & Voogt, 2014; Voogt et al., 2015). Participation in co-design has also been shown to deepen teachers' reflexive practices, broaden their perspectives, change their beliefs about teaching and confidence in their own teaching, serve as a support system or social network, and function as a form of professional development (Voogt et al., 2011). In addition, co-design partnerships that include disciplinary experts may provide a context for these professional scientists and engineers to develop their own pedagogical practices (AAAS, 2013; The Design-Based Research Collective, 2003).

Different approaches of collaborative design have emerged that center teacher and student learning. These co-design models occur across contexts, formats, and scales, from in-person collaborations between several teachers at a school to state-wide asynchronous online collaborations among teacher-designers. In this review, four common forms of co-design communities are highlighted: school-based professional learning communities (PLCs), lesson study groups (based on the Japanese lesson study model), teacher design teams (TDTs; a Dutch model), and research-practice partnerships (RPPs).

Co-design through School-based Professional Learning Communities

School-based professional learning communities (PLCs) are a model in which “teachers work together and engage in continual dialogue to examine their practice and student performance and to develop and implement more effective instructional practices” (Darling-Hammond & Richardson, 2009, p. 49). Several authors point to the collaborative design of lessons and formative assessments as a common, though not singular, activity of PLCs (DeFour & Reeves, 2016; Jacobson, 2010; Newmann, Kruse, Louis, & Bryk, 1994). For example, collaborative lesson design is a critical component of Jacobson’s (2010) common priorities approach to PLCs, explaining that “professional development is often wasted when teachers don’t have the opportunity to implement changes in the classrooms” (Jacobson, 2010, p. 44). Jacobson (2010) also states that along with effective coaching and common assessments, "collaborative lesson-design projects tend to encourage teachers to address more ambitious goals, such as critical thinking skills and transfer skills" (p. 44). In PLCs, the collaborative design of lessons or units is just one of many possible activities taken up in these learning communities but is often not their explicit purpose.

Co-design through Lesson Study

The Japanese model of Lesson Study (*jugyo kenkyuu*) is an action-research oriented approach toward the design, piloting, peer-observation, critique, and improvement of lessons (Hanford, 2015; Lewis, 2000). Lesson study is an approach to solving particular problems of practice. The approach was popularized in Japan, and has since been implemented in the U.S., UK, and other countries since the early 2000s. Groups of teachers in a school, often triads of teachers of the same subject and/or grade level, come together around a teaching problem with a plan-observe-reflect-plan model (Teacher Development Trust, n.d.). The teachers first research the existing literature on the topic, and may consult with an outside advisor such as a researcher or content expert (Hanford, 2015). The teachers then co-design a lesson and one teacher volunteers to teach the new lesson while the others observe what is known as a public research lesson (Hanford, 2015; Lewis, 2000). During these peer observations of the piloting, the observers focus on the students' experience with the content, with an eye toward iterative cycles of improving the lesson. A colloquium may follow, in which the lesson, recorded data, and comments are analyzed and discussed (Lewis, 2000).

Co-design through Teacher Design Teams

The Dutch model of Teacher Design Teams (TDTs) makes curriculum design the main focus of teacher communities within schools. Binkhorst, Handelzalts, Poortman, and van Joolingen (2015) define the Dutch model of a TDT as "a type of PLC with a specific focus on (re)designing educational materials" (p. 214). TDTs consist of at least two teachers who teach similar subjects and are interested in improving their professional practice (Velthuis, Fisser, & Pieters, 2015). Usually, TDTs are school-based but there has been some models of networked TDTs with membership from across local schools. TDTs have been investigated as a way to understand teacher learning (Voogt et al., 2011), increase science teachers' self-efficacy (Velthuis, Fisser & Pieters, 2015), and understand the role of facilitators in the design process (Binkhorst, Handelzalts, Poortman & van Joolingen, 2015; Voogt et al., 2011). While PLCs are focused generally on transforming teacher practice and improving student achievement, TDTs instead are focused on designed curriculum materials as the outcomes of the group's efforts, along with changes in teacher practice.

The collaborative nature of curriculum design and the community fostered within a TDT has the potential to transform teacher practice and professional norms. Velthuis, Fisser, and Pieters (2015) suggest that "the work in the team is supposed to change the way teachers work and interact, contributing to organizational change at both the school-cultural level and the school structural level" (Handelzalts, 2009 as cited in Velthuis, Fisser, & Pieters, 2015, p. 219). Research on TDTs often takes the form of educational design studies (e.g., Velthuis, Fisser, & Pieters, 2015).

Co-design through Research-Practice Partnerships

Whereas PLC, Lesson Study, and TDT approaches are teacher-centered and teacher-driven, a different model to co-design expands the design community to include professionals who offer diverse forms of expertise. Within Research-Practice Partnerships (RPPs), complex, often multi-tiered teams may engage in curriculum design together. As a type of university-school partnership, these design-focused RPPs bring together university researchers, teachers, school/district administrators, and often, disciplinary experts (e.g., scientists, mathematicians, engineers) in collaborative efforts to transform teaching and learning through the (re)design of educational materials or technologies. These types of partnerships, while often university-initiated, seek to redefine unidirectional conceptions of bringing research to practitioners, and instead, aim to bridge research and practice. RPPs that are focused on the design of curricular innovations are known as design-based or design-focused RPPS (design-RPPs; Coburn, Penuel, & Geil, 2013). These design-RPPs often use design-based research (DBR) or design-based implementation research (DBIR) methodologies to guide their collaborative work as the teams engage in design and research activities organized by iterative cycles of design-enact-redesign (The Design-Based Research Collective, 2003). Design-RPPs will be explored in more depth throughout this chapter.

A comparison of some of the features of collaborative curriculum design across these four common professional learning models is provided in *Table 2.*

Table 2. Common Features of Professional Learning Models for Curriculum Co-design

Feature	PLCs*	Lesson Study	TDTs*	RPPs*
Context	School based.	School based.	School based or networked across district.	Often university initiated. University or school based.
Membership	Teachers, sometimes with facilitator.	Teachers, often in triads.	Teachers, often with facilitator.	Inter-institutional. May be multi-tiered. Administrators, teachers, researchers, experts.
Outside Expertise	Study groups may consult literature.	Often consult research literature and outside experts.	May consult with content experts.	Partnership with researchers and disciplinary experts.
Peer observations	Observe each other's classes.	Peer observations of "public research lessons".	N/A	Intense study of curriculum enactment through iterative cycles of DBR.
Curriculum design	Co-design of lessons or formative assessments for common use at school.	Co-design of lessons to solve a problem of practice.	Individual or co-design for own classroom use.	Co-design in inter-professional and cross-practice teams, in response to opportunities of practice, often reform-oriented. For wide dissemination.
Curriculum enactment	Uncertain.	Process of piloting, peer observation, analysis, and refinement.	Some TDTs may include lesson implementation, many are only focused on (re)design.	Iterative cycles of design, reflexive enactment, and re-design.
Designed curriculum	For teacher or school use.	For teacher and school use.	For teacher or school use.	For school use and broadly disseminated, often nationally.

*PLCs are defined as professional learning communities. TDTs are defined as Teacher Design Teams. RPPs are defined as research-practice partnerships. DBR is defined as design-based research.

Historical Foundations of Partnerships in Science Education

It is helpful to understand some of the broad historical factors that influenced the rising interest in partnerships as contexts for curriculum design in science education. Linn, Songer, and Eylon (1996) identified three historical periods in science teaching and learning: the Separation Period (1870-1950), the Integration Period (1950-1975), and the Partnership Period (1975-late 1990s). In the Separation Period, teachers, psychologists, and scientists worked separately within their fields in the absence of cross-disciplinary collaborations. Most science curriculum materials were developed by scientists. During the Integration Period, the science education reforms of the 1950s spurred scientists to begin to collaborate with teachers and psychologists. In the Partnership Period, continued calls for reform in science education led to partnerships between education psychologists, researchers, natural scientists, technology experts, and K-12 science educators to study learning, learning environments, and curricula—with a focus on students' disposition to learn and the nature of instruction (Linn, Songer, & Eylon, 1996). Much of the focus of these partnerships was to understand how to design science instruction that would be accessible to all students, with an acknowledgement of how science education has previously discriminated against women and racial minorities (Linn, Songer, & Eylon, 1996). Major shifts in the Partnership Period included a focus on the importance of the social environment on science learning, the acknowledgement of the damaging effects of limited views of who can and should do science (i.e., white men), and a focus on science learning as knowledge integration;

the major convergence was the call for cross-professional practices, which began to garner funding support from federal agencies and grant programs (Linn, Songer, & Eylon, 1996).

University-School Partnerships as Contexts for Co-Design

University-school partnerships surfaced as a way of engaging researchers, content experts, and teachers during this Partnership Period of science education. In general, university-school partnerships can be conceptualized as a formal partnership between a university and at least one school or district in which the university's expertise in supporting pre-service and in-service teachers, the schools expertise in areas of schooling, and the district's ability to support them both are leveraged and applied toward a mutual purpose (Goodlad, 1988). When they are effective, these types of partnerships become "symbiotic" as they bring together "institutions that need each other for the solution of tough problems" of teaching, learning, and schooling (Goodlad, 1988, p. 26). These partnerships can take on many scales, including large networks of university-school partnerships.

Contemporary university-school partnerships work to bridge theory and practice, in contrast to the unidirectional translation metaphor of bringing research findings *from* university researchers *to* practitioners (Penuel, Bell, Bevan, Buffington, & Falk, 2016a). Penuel, Allen, Coburn, and Farrell (2015) point out that "researchers and practitioners working in partnership are engaged in processes of collaboration and exchange that are both messier and potentially more transformative than the one-way translation of knowledge of research into practice" (Penuel, Allen, Coburn, & Farrell, 2015, p. 183). University-school partnerships are seen as a way to bridge these worlds by bringing together researchers and practitioners in joint work that is mutualistic and reciprocal, which often requires the partners to "invent new formats for working together" (Penuel, Coburn, & Gallagher, 2013).

However, a cultural-historical perspective on these partnership reminds us that they are situated in larger contexts rooted in cultural, social, economic, political, and historical dimensions which create and sustain a "hierarchy model" in the relations between university researchers and practitioners (Gee, 2001 as cited in Carlone & Webb, 2006). While the translation metaphor may be replaced with one of bridging, issues of power, authority, and status are still of concern in university-school partnerships (Carlone & Webb, 2006; Penuel, Coburn, & Gallagher, 2013; Penuel et al., 2016a). As Carlone and Webb (2006) discovered, disrupting the hierarchy model of university and school relations is no easy task. Despite their best intentions to create a science-focused co-design partnership between university researchers and elementary school teachers that would overcome the hierarchy model through a focus on "collaborative labor", they ended up reproducing it instead through the group's language, actions, and interactions (Carlone & Webb, 2006). Drawing on the work of Larabee (2003 as cited in Carlone & Webb, 2006), these researchers considered how the binaries of normative versus analytical, particular versus universal, and experiential versus theoretical serve to create the worldviews of teachers and researchers that are at odds. These tensions, along with issues of identity and who gets to do and learn science, may reinforce issues of power and authority (Carlone & Webb, 2006). Politics also present challenges, considering that university-school partnerships exist within the political context of the university and the school district, as well as larger systemic reform efforts (Coburn & Penuel, 2016).

Research-Practice Partnerships in Education

Research-practice partnerships (RPPs) are a particular type of university-school partnership. RPPs are not unique to education; rather this partnership structure has been developed in fields including public health, mental health, youth development, and criminology

(Coburn & Penuel, 2016). RPPs across settings are long-term, complex, inter-institutional, cross-practice, and often multi-tiered teams that include practitioners and researchers focused on investigating and navigating opportunities of practice (Coburn, Penuel, & Geil, 2013). RPPs in education are “long-term collaborations between practitioners and researchers that are organized to investigate problems of practice and solutions for improving schools and school districts” (Coburn & Penuel, 2016, p. 48). RPPs consist of partnerships between multiple organizations which may be conceptualized as multi-tiered relationships consisting of overlapping spheres of activity systems. For example, Severance, Leary, and Johnson (2014) mapped the activity structures of a RPP focused on the design and implementation of a digital platform for mathematics education as those of the teacher-designers, the district, and the researchers. The focus of a RPP in education may include collaborative design of curriculum materials or educational technologies, but not always (e.g., Carlone & Webb, 2006; Coburn, Penuel, & Geil, 2013; Engle, 2008; Linn, Shear, Bell, & Slotta, 1999; O’Neill, 2016; Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013; Severance, Penuel, Sumner, & Leary, 2016; Shear, Bell, & Linn, 2004).

Specifically, RPPs in education are: a) multi-year collaborations that are sustained through multiple projects; b) focused on and driven by persistent problems of practice; c) are mutualistic; d) employ strategies to structure interaction such as tools, routines, and protocols; and e) involve participants in collecting and analyzing original data about the partnership and its outcomes (Coburn & Penuel, 2016). Researchers and practitioners in RPPs engage in *joint work*, in which "both district goals for improvement and aspects of the research are defined and evolve through interaction, rather than being planned fully ahead of time or defined by either researchers or practitioners independently of one another" (Penuel et al., 2015, p. 183). Many

RPPs are focused on systemic change at district, state, or national levels however they can occur across settings and scales (Coburn & Penuel, 2016; Coburn, Penuel & Geil, 2013). Not all RPPs include university researchers, however RPPs that function as university-school partnerships are the focus of this inquiry.

Participatory Design Research Traditions

Research-practice partnerships that are focused on curriculum design have their roots in participatory design traditions. Co-design of curriculum materials is a type of cooperative or participatory design approach, in which the intended users of the materials—the teachers—are fully brought into the design process. Moreover, with some approaches to co-design, the teachers are both co-authors and enactors of the materials as they pilot the materials in their own classrooms to provide feedback that will inform curriculum revisions and allow data collection activities on the part of researchers. In this section, I will review several participatory models for design, touching on co-design's Scandinavian roots.

Design across professions. Design has long been recognized as the work of architects, engineers, musicians, visual and performing artists, and craftsmen. Cross (2011) reminds us that design was once "a collective or shared ability" that relied on distributed expertise among a community, and that only recently through the emergence of the design professions has design and design thinking been treated as "a kind of exceptional talent" held by the individual (p. 4). However, given the increasingly complex nature of modern design problems, interdisciplinary teams are often needed so that design occurs as "a social process of interaction and negotiation between the different participants" (Cross, 2011, p. 20). Each of the design fields has developed their own signature approaches to design, some of which include more participatory and democratic models. For example, community design charrettes are common in the fields of architecture and urban planning. User-centered and human-centered design approaches are taken in some engineering and computer science disciplines; this focus has even spawned a new interdisciplinary specialty in human centered design and engineering.

Design thinking, the strategies used by professional designers, has recently gained popularity as a set of conceptual tools to help people engage in design thinking to solve problems and develop creative solutions. By taking design out of the design professions and into the hands and minds of people, design thinking becomes a tool of the people. Organizations like the Stanford d.School and IDEO develop design thinking tools, resources, and classes to help professionals across fields develop their “designerly” mindsets for approaching “wickedly complex” and open-ended challenges (Cross, 2011). Design thinking has increasingly become a tool for educators as well, with teaching being conceptualized as design work. For example, the design firm IDEO partnered with Riverdale Country Schools in New York City to explore how to use design thinking as a way to approach problems in their classrooms and schools. Their artifact, the *Design Thinking for Educators Toolkit,* is a workbook that supports teachers and administrators in applying design thinking to challenges related to curriculum, space, processes, tools, and systems (IDEO, 2012). Design writ large continues to become increasingly social and participatory.

Cooperative design. Toward the beginning of the Partnership Period in science education in the 1970s and 1980s, Scandinavian designers developed an approach to design called *cooperative design* that was rooted in a socio-political context of “industrial democracy and strong union relationships” (Bødker, Grønbæk, & Kyng, 1993, p. 157). This is a participatory design process that includes “full [not just token] participation from the users—both from a democratic point-of-view and to ensure that competencies central to the design are represented by the design group" (Bødker, Grønbæk, & Kyng, 1993, p. 158). For example, Bødker, Grønbæk, and Kyng (1993), professors of computer science at Aarhus University in Denmark, took a cooperative design approach to systems design of workplace computer applications. Traditionally, designers would design a computer system, and then when it was ready, test it with users or employ it without testing. However, cooperative design engages users throughout the entire design process. Through the theoretical lens inspired by activity theory and Engeström's Developmental Work Research (see Cole & Engeström, 2007), these researchers aimed for full participation of users in the design process, while at the same time acknowledging and organizing around the power differentials, conflict, and politics that they believe are inherent in work places. Bødker and her colleagues (1993) viewed cooperative design as a sociomaterial process in which they organized design sessions so that designers and users created and interacted with design artifacts—mock-ups and prototypes—in a game-like atmosphere. Engaging with workers who are the future users of the computer applications being designed, the designers engaged them by first making observational visits to their workplaces and interviewing them. The researchers then held design workshops that included the stages of Futures Workshop, Organizational Games, and Embodying Ideas. In Future Workshops, participants engaged in the phases of Critique, Fantasy, and Implementation, in which they identified the problem, freely imagined an alternative workplace, and identified the resources that would be needed to make such a change. In these workshops, talk and chart paper become the mediating artifacts, in a way akin to Engeström's (2008) concept of future-oriented *where to* artifacts. In the next two stages, researchers and users cooperatively created and interacted with mock-ups and prototypes. Cooperative interaction with these physical design artifacts allowed the group to "transcend the borders of reality and imagine what is currently impossible" (Bødker, Grønbæk, & Kyng, 1993,

p. 168). The thought is that through cooperative design, better products are created that are more in-tune with the needs and desires of the actual intended users, rather than the whims and assumptions of the designers.

Community-based and participatory design research. Though the participatory design process of cooperative design was developed with workers in union-shops, this Scandinavian design tradition was one of the inspirations for co-design within design-based research (Severance, Penuel, Sumner, & Leary, 2016). In particular, the ideals of workplace democracy, and the attention given to power differentials and tensions in the participatory design process offer insights into the collaborative approaches of design-RPPs (Severance, Penuel, Sumner, & Leary, 2016). Bell (2004) describes participatory design as an approach for linking ethnography with design through “anthropologically-driven” design-based research. Engaging participants/users in this way “provides them with a voice and a source of influence on shaping changes to their settings” (Bell, 2004, p. 249). As O’Neill (2016) cautioned, client-centered design, in which users or community members are engaged only at the beginning of the design process, is not enough. To this end, learning scientists are currently developing new critical approaches to participatory design and research that “deliberately work to disrupt or create new roles and relations to achieve transformative ends” (Bang & Vossoughi, 2016). For example, Community-Based Design Research (CBDR) is a “reworking of design-based research methods because it privileges and centers the work in community, engages broad ranges of community members, and is driven by community members in key project staff positions” (Bang, Faber, Gurneau, Marin, & Soto, 2015, p. 4). As another example, Participatory Design Research (PDR) is an approach to collaborative, justice-oriented design that attends to how critical historicity, power, and relational dynamics “shape processes of partnering and the possible forms of learning that emerge in and through them” (Bang & Vossoughi, 2016, p. 174).

Collaborations within thought communities. While much of the research into workplace collaboration and design focus on relatively short term work groups in factories, offices, and other traditional work settings, John-Steiner (2000) investigated long-term collaborations in art studios, laboratories, and concert halls. She suggested another way of thinking about collaboration and design is through an examination of sustained, committed, interdependent partnerships, such as the creative collaboration between the musicians in a string quartet or the intellectual collaboration of research partners in a science laboratory. John-Steiner (2000) investigated creative partnership, those joined lives that lasted for decades, through the perspectives of Vygotskian cultural-historical theory (e.g., Cole & Engeström, 2007) and feminist theories. Her stance was that “generative ideas emerge from joint thinking, from significant conversations, and from sustained, shared struggles to achieve new insights by partners in thought” (John-Steiner, 2000, p. 3). She stated that our changing, interconnected, globalized society has created a “period of ‘necessary interdependence’” that requires new forms of collaboration which she called *thought communities* (John-Steiner, 2000, p. 3). In these types of long-term partnerships, a zone of proximal development allows each partner to learn and be stretched by the other’s thinking. Forms of shared language and social practices emerge as mediated through cultural tools and collaborative tools (John-Steiner, 2000). While co-design within a design-RPP is unlikely to form the type of long-term creative partnership that John-Steiner studied, her work is of interest in particular due to the attention she gives to the emotional aspects of collaboration, a dimension often left out of the relevant learning theories. This includes joint interest, the development of trust and confidence, a “lowering of the boundaries of the self", and the emergence of a sense of "we-ness" along with an acknowledgment of the roles of tensions, conflict, and even separation in partnerships (John-Steiner, 2000, p. 190).

The design of curriculum materials through design-based research approaches and situated in the context of a design-RPP is a contemporary approach to partnerships that seeks to design instruction through cross-professional collaboration. Over the past decade, researchers have developed, attempted, and studied various approaches to collaborative design in RPPs. For example, Engles' (2008) DBR investigation of principles for fostering productive collaboration in the co-design of middle school mathematics curricula in the MMAP project, or the exploration of partnership models, activity structures, and guiding principles for co-design of middle school science curricula with the Deformed Frogs partnership (Linn, Shear, Bell, & Slotta, 1999; Shear, Bell, & Linn, 2004). In Part II, I will narrow my focus to summarizing conceptual frameworks and theoretical lenses for understanding the complex work that occurs within design-focused research-practice partnerships in science education.

Part II: Design-focused Research-Practice Partnerships in Education

In this section, I will discuss how participants in design-based research-practice partnerships encounter sociocultural boundaries and how they may use tools, routines, objects, and people to negotiate and cross these boundaries in order to engage in joint work. Given that design-based research-practice partnerships are collaborations of people working across different professions, practices, and institutions, I will describe several learning theories that provide helpful theoretical lenses for understanding interdisciplinary work teams. Cultural-historical activity theory, its relational turn, and social practice theory will be examined. Finally, I will argue that design-based research is an appropriate methodology for supporting and studying curriculum design through partnership.

Design-focused Research-Practice Partnerships in Education

Design-focused RPPs provide a context for reform-oriented, co-design of curriculum materials by bringing together researchers, practitioners, and disciplinary experts with varying types of expertise in a design community (e.g. O'Neill, 2016; Penuel, Coburn, & Gallagher, 2013; Penuel et al., 2015; Severance, Penuel, Sumner, & Leary, 2016). These design-RPPs are often guided by design-based research (DBR) (Bell, 2004; Bell, Hoadley, & Linn, 2004; The Design-Based Research Collective, 2003) and design-based implementation research (DBIR) methodologies and have the common goal of addressing a persistent problem of practice through the collaborative design, enactment, and revision of curriculum materials. The design team is comprised of members of the multi-tiered partnership, which may consist of participants from one or more tiers, such as including both teachers and researchers. A major assumption of design-RPPs is that the distributed expertise of the team can be leveraged during design work.

Common challenges in design-RPPs. When people come together around the design table to collaboratively design an educational intervention, this work can be generative, expansive, and transformative; it can also be difficult, as people come together from different institutions, each with their own cultures and norms of professional practice. Common partnership challenges include differing ideas about the focal problem, lacking a common language or work practice among participants, having to adapt to atypical norms of interaction and divisions of labor, developing trust in each other and the process, and holding different and at times conflicting expectations for the project (Coburn & Penuel, 2016; Penuel, Coburn, & Gallagher, 2013). In multi-tiered RPPs in which both district and school leaders are engaged, challenges can arise from complex organizational structures, high turnover in staff, and the fact that these partnerships exist within a politicized environment consisting of multiple interest groups (Coburn & Penuel, 2016). Issues of power, authority, and status can come into play in these partnerships, reinforcing the model of hierarchy that has plagued university-school partnerships (Carlone & Webb, 2006; Coburn & Penuel, 2016; Penuel, Coburn, & Gallagher, 2013; Penuel et al., 2016a). This has led some researchers to investigate how to democratize design-RPPs, “amplify teachers’ voices”, and foster teacher agency within the design community (Carlone & Webb, 2006; Penuel et al., 2016a; Severance, Penuel, Sumner, & Leary, 2016). In addition to partnership challenges, design-RPPs are faced with multiple design decisions and tensions as they work together to create innovative instructional materials (e.g. Severance, Leary, & Johnson, 2014).

Concepts of boundaries and boundary crossing. When people come together to work on a shared project, especially when they come from different work groups or institutions, the coordination of multiple perspectives and social practices is complex work. The social practices involved are different than those of legitimate peripheral participation and other situative learning theories, which suppose that learning and interaction occur within a well-bounded community of practice (e.g. Lave & Wenger, 1991; Wegner, 1998). Rather, these practices are “historically accumulated, knowledge-laden, emotionally freighted, and given direction by what is valued by those who inhabit them” (Edwards, 2012). When people move between work groups or come together from multiple institutions for collaborative work, they enter into potentially new social practices (Dreier, 2016) and encounter sociocultural differences. Each person is situated within their own work environment, which itself is rooted in and influenced by social, cultural, historical, political, and economic dimensions, and comes to the collaborative project with their own professional identities, beliefs, and norms. At the scale of a design-RPP, the members in the partnership represent their institutions—university, district, and school—with diverse and divergent cultures. As the partners engage in *joint work* (e.g. Darling-Hammond & Richardson, 2009; Little, 1990; Penuel, Coburn, & Gallagher, 2013; Penuel, et al., 2015), they may bump up against *boundaries*, which can be defined as "multiple cultural, professional, and organizational differences" (Penuel, Allen, Coburn, & Farrell, 2015, p. 188) or as "sociocultural differences leading to discontinuity in action or interaction" (Akkerman & Bakker, 2011, p. 1). Boundaries are differences in perspectives or practices, for example, between and within organizations, work groups, professions, disciplines, or between research and practice (Akkerman & Bakker, 2011; Penuel et al., 2015) and can include differences in knowledge, norms, or power (Akkerman & Bakker, 2011).

These boundaries, or sociocultural differences, can be viewed as an opportunity for or a challenge to collaboration. Goodlad (1988) colorfully describes the cultural differences between schools and universities as "both the promise of a productive school-university partnership and the sandtraps, swamps, and quicksands standing in the way of a successful marriage" (p. 14). In contrast, Penuel and his colleagues (2015) are careful to point out that the sociocultural differences represented by these boundaries "are viewed not as obstacles to be overcome, but as value inherent to social and professional activity" (p. 187). Similarly, Akkerman and Bakker (2011) comment on the momentum within the research community to view boundaries as spaces for expansive and generative learning.

This space, rich with opportunity and possibly fraught with challenges, is known as a *boundary space* (Edwards, 2011). Edwards (2011) describes this as a space "where the resources from different practices are brought together to expand the interpretations of multifaceted tasks"

(p. 34). A boundary space may be thought of as the space between or the weaving together of what Wenger (1998) calls the *boundaries* and *peripheries* of communities of practice, where boundaries are discontinuities and lines of distinction and peripheries are areas of overlap and connection. Penuel, Coburn, and Gallagher (2013) describe this space in a more hopeful light than Goodlad (1988), conceptualizing it as a *trading zone*, a “social space where people can debate and exchange ideas, and also material spaces where people engage in various forms of ‘placemaking’” which can include building different types of partnerships (p. 238). The concept of *boundary work* captures the ways in which people negotiate, coordinate, and create new social practices as they engage in this joint work (Penuel, Coburn, & Gallagher, 2013).

Joint work at the boundaries of partnership. Penuel and his colleagues (2015) conceptualize the collaborative, inter-institutional work of design-RPPs as *joint work at the boundaries*. Each of the institutions represented in a RPP are “distinct cultural communities” (Penuel et al., 2015, p. 183). When people from these communities come together for joint work around the figurative design table, in what Wenger (1998) calls a *boundary encounter*, they must navigate their and others’ cultural and professional norms while developing new ways of working together. All the while, they remain “semi-autonomous outside the space of the trading zone” (Penuel, Coburn, & Gallagher, 2013, p. 239). When the focus of a team is co-design, Penuel, Coburn, and Gallagher (2013) explain that they must invent and negotiate new roles, norms, procedures, and divisions of labor for their joint work that may differ from the ways that they act and are perceived at their home institutions, outside of the boundary space or trading zone. Akkerman and Bakker (2011) investigated the learning that can occur at the boundaries. In a review of 182 research studies, they identified four types of learning that occurs at boundaries: *identification* of intersecting practices, *coordination* of practices, *reflection* on practices by taking on others' perspectives, and *transformation* of practices or the creation of boundary practices (Akkerman & Bakker, 2011).

Boundary crossing. When sociocultural differences are viewed as boundaries between territories, rather than obstacles, they are meant to be negotiated and crossed (Penuel et al., 2015). Joint work requires members of a design team or partnership to engage in *boundary crossing*, which can be characterized as "an individual's transitions and interactions across different sites of practice" (Akkerman & Bakker, 2011 as cited in Penuel et al., 2015). Boundary crossing may consist of identifying and recognizing boundaries and taking specific, intentional *moves* to find areas of common ground and pathways for joint work (Penuel et al., 2015). Over time, groups also coordinate their work by developing a repertoire of practices that is specific to the group and their shared purpose and which connects the members of the group (Wenger, 1998). Boundaries can be crossed by people, objects, and through interactions between people with different practices (Akkerman & Bakker, 2011). Design-RPPs are "often organized around specific boundary objects or boundary practices that enable collective change through the coordination of activity across the different tiers" (Penuel et al., 2016a, p. 260). It is these objects, practices, moves, and interactions that a team develops and negotiates together that allows for boundary crossing to occur.

People can also facilitate boundary crossing through their use of *boundary objects,* conceptualized as the nexus of multiple perspectives within a community of practice (Bowker, Timmermans, Clarke, & Balka, 2016; Leigh, Star & Griesemer, 1989; Wenger, 1998). Boundary objects are the "nexus of perspectives" that coordinates the multiple perspectives within a community of practice (Wenger, 1998, p. 107). Boundary objects can be but are not necessarily physical artifacts; they can be documents, memos, forms, computer systems, tools, terms, and concepts; even a forest can function as a boundary object that coordinate the practices of the different groups who have a vested interest in it (Wenger, 1998). For example, in a design-RPP studied by Penuel, Coburn, and Gallagher (2013), boundary objects included the conceptual framework *How People Learn* and the FOSS science kits that they were redesigning. As "nexus of perspectives", the teachers and researchers had different perspectives on these objects, but they coordinated these perspectives around a set of common goals for curriculum design. Designed artifacts have the potential to become boundary objects. Wenger (1998) encourages designers to consider how their designed artifacts may act as boundary objects to connect the designers' community of practice with the communities of practice of the user of that artifact (p. 108).

*Boundary practice*s are described as routines and tools that allow for equitable collaboration, specifically those which "bridge the practices of researchers and those of practitioners as they engage in joint work" (Penuel, Allen, Coburn, & Farrell, 2015, p. 190; Penuel, Coburn, & Gallagher, 2013; Wenger, 1998). Penuel and his colleagues (2015) suggested the intentional development of boundary practices within RPPs, noting that "although some boundary crossing is impromptu and occasioned by the need to make sense of emerging issues and concerns, it is possible to build in structures and routines that provide sustained opportunities for boundary crossing" (p. 192). As a team figures out how to collaborate and engage in joint work together, they will create new boundary practices; however, it is important that they also make "explicit use of practices that are 'native' to each culture" (Penuel, Coburn, & Gallagher, 2013, p. 250). In RPP design communities, co-design is the main boundary practice and the designed educational innovations—curriculum materials or technologies—serve as boundary objects.

People can facilitate boundary crossing through their invention, negotiation, and use of boundary practices and boundary objects. However, an individual can also be the source of boundary crossing by bridging the work of the partnership with their home institution, or by bridging more than one institution represented in a partnership. The role of a *boundary spanner* is critical in many RPPs as it facilitates mutually beneficial interactions between the researchers and practitioners in the partnership (Penuel et al., 2016a). The boundary spanning role has been described in the literature on RPPs and teacher professional learning communities as a “go-between”, “translator”, “hub of communication”, “buffer”, “broker”, and “boundary crosser” (e.g., Akkerman & Bakker, 201; Ford & Youngs, 2017; Penuel, Coburn & Gallagher, 2013; Russ, Sherin, & Sherin, 2016; Wenger, 1998). A boundary spanner may belong to more than one sub-unit in an organization, thus spanning the boundaries between them. A boundary spanner may act as a conduit of information between their institution and the other members of a research-practice partnership or may have one foot in the door of the institutions that make up the partnership. A boundary spanner may also function in a communication role, translating the specialized, hybrid language of the partnership to the broader community, which is especially important for implementation and dissemination of educational innovations. Not much is known about the social and institutional structures that may support or constrain a boundary spanner’s ability to cross boundaries and facilitate joint work, though some researchers have made this the focus of their inquiry. For example, in their study of a university-school partnership, Penuel, Coburn, and Gallagher (2013) observed a district math coach, who was a member of the design-RPP, become a graduate student for one of the researchers in the partnership. This boundary spanner physically crossed over from one institution in the partnership to the other and was able to span both the perspectives and professional practices of a teacher and a researcher. As a second example, Engeström's (2008) ethnographic study of a school-based teacher design team used cultural-historical activity theory (CHAT) to examine the boundary crossing that occurred during five teacher's joint work at the boundary. These elementary school teachers were motivated to collaboratively design and enact an integrated K-6 curriculum focused on global education. In this work, the teachers encountered, questioned, and crossed the "taken-for granted" boundaries of grade levels, classroom spaces, temporal units, and curricular subjects (Engeström, 2008, p. 88). The teachers also redefined their norms around their roles, division of labor, discourse, and school rules (Engeström, 2008). Cultural-historical activity theory and other relevant theories will be highlighted in the next section.

Theoretical Lenses for Understanding Co-design

Sociocultural, situative, and cultural-historical theories have been used to understand workplace learning, collaboration, and design. Recent studies on co-design have been grounded in cultural-historical activity theory (CHAT) (Engeström 2001, 2008), expansive learning (Engeström, 2001), knotworking (Engeström, 2008), social practice theory (Holland & Lave, 2009), and social network theory (Muijis, Ainscow, Chapman, & West, 2011). In this section, I will provide an overview of cultural-historical activity theory (CHAT), discuss the relational turn in CHAT that provides insights into how people coordinate their thinking and practice in collaboration, and summarize relevant aspects of social practice theory. Expansive learning will be described in Part III. These theories consider how the individual and the group function within activity systems, including across the boundaries of professions, practices, and institutions.

Cultural-Historical Activity Theory (CHAT). Third generation activity theory, also known as CHAT, provides a framework for understanding how teams engage in joint work both within and across institutions. It is helpful to understand how activity theory has evolved over time and how contemporary researchers are continuing to develop the theory today. Activity theory is rooted in the theories of Russian cultural psychologist Vygotsky of the 1920s and early 1930s when first generation activity theory was developed with a focus on the culturally mediated activity of an individual. Vygotsky's theory was further developed by his student and colleague Leont'ev, with his works published in the 1970s. The focus of second generation activity theory was on object-oriented actions within a collective activity system (Engeström, 2001). Here, the *activity system* is the unit of analysis. Leont'ev's ideas were taken up by European and North American researchers in the 1970s, with a particular interest in studying workplaces (Edwards, 2005; Engeström, 2001). However, a criticism of this conceptualization began to bubble to the surface of the research community. Cole and other researchers in the late-1980s challenged the ability of second generation activity theory to recognize, acknowledge, and understand cultural diversity among activity systems or allow for analysis of interactions between more than one activity system (Engeström, 2001). These criticisms drove the development of a third generation of the theory.

Third generation activity theory developed out of Bakhtin and Wertsch's ideas about dialogicality, the idea that more than one activity system could interact with each other, and the concept of boundary crossing (Engeström, 2001). This third generation became known as cultural-historical activity theory (CHAT) and has spawned an entire field of research that employs CHAT as both theory and methodology. In a CHAT diagram of two interacting activity systems, the top of each triangle includes more obvious tools and symbols, while the lower part of the triangle incorporates less obvious social mediators (Engeström, 2008). An activity system occurs at different scales, such as the activity system of a classroom, science department, school, or district (Engeström, 2008). Vygotsky's (1978 as cited in Engeström, 2008) concept of the zone of proximal development can be applied here, as the developmental potential of two or more activity systems interacting with each other. Engeström (2001) explains that the object of activity shifts from first being a "raw material" of one activity system, to becoming a "collectively meaningful object constructed by the activity system", to then possibly becoming a "shared or jointly constructed object" between the two activity systems.

Engeström (2001) identified five principles of CHAT. First, the unit of analysis is an activity system interacting with one or more other activity systems. Second, each activity system is *multi-voiced*, which refers to the diverse perspectives held by members of each activity system, as shaped by the division of labor, roles, artifacts, and norms of the activity system, as well as each individual's own history. Engeström (2001) describes this multi-voicedness as both "a source of trouble and innovation, demanding actions of translation and negotiation" (p. 136). Third, activity systems have *historicity*. They are *multi-layered* and are shaped over time (Engeström, 2008). They can only be understood through a historical lens that examines their own local, micro history, such as that of a classroom, but also the macro history of the theories, tools, concepts, and procedures of its larger context, such as the school district or K-12 schooling writ large (Engeström, 2001, 2008). Fourth, CHAT sees *contradictions* as the engine of change within and between activity systems. Contradictions are defined as "historically accumulating structural tensions" between the parts of the activity system that can drive disturbances, innovation, and transformations of activity (Engeström, 2001, p. 137; Engeström, 2008). Lastly, Engeström (2001) proposes that activity systems have the possibility of "expansive transformations" where, through collaboration across activity systems, the object of activity is re-conceptualized and expanded into a new practice, which can be a new pattern of cultural or work activity. Engeström's (2001) concept of expansive learning captures this final CHAT principle and is particularly helpful when the object of activity is unfolding and unknown and the forms of activity must be invented or learned.

Engeström's (1987 as described in Engeström, 2001, 2008) theory of expansive learning is envisioned as a cycle or spiral of "expansive transformations" between activity systems. The cycle begins with questioning of an accepted practice and generates new stable forms of practice or theoretical concepts by crossing the boundaries of the activity systems. During expansive learning, the activity system's multi-layered, multi-voiced, and historical dimensions drive innovation as work teams tackle culturally new problems. In this process, the object of activity is expanded and re-conceptualized. In particular, expansive learning can apply to established teams involved in multi-year partnerships, although Engeström (2008) cautions against an "iron cage" conception of teams, as they are always fluid and ever in flux, like a spider "web in the wind" (p. 193). Expansive learning may occur in the activity systems of a design-RPP, as its members collaborate to identify, envision, and produce solutions to recognized problems of practice. Expansive learning is also discussed in Section III of this chapter.

Knotworking is a concept that applies most to temporary work groups who come together (knot tied) to solve an immediate problem, and then disband (knot untied). Less stable even than the "web on the wind" these teams are "rapidly pulsating, distributed, and partially improvised" as they expand and contract in size and expertise, and change and morph as needed to solve a problem (Engeström, 2008, p. 194). The knot of activity is tied from "loosely connected actors and activity systems", so the knot does not hold. In knotworking, the threads of activity are untied and re-tied again and again in response to the changing needs of the problem and solution, in a longitudinal process that can span the trajectory of a design problem (such as a product or service) (Engeström, 2008). As shown in Chapter Five, knotworking provided a conceptual tool for understanding how work teams form, change, expand, contract, and dissolve within the larger context of a research-practice partnership. With the lens of knotworking, the researcher recognizes the dynamic, boundary crossing nature of collaboration.

Difficulties in collaboration: A CHAT perspective. CHAT also provides insights into the challenges of collaboration. As described previously, design RPPs encounter partnership challenges, design tensions, and issues of hierarchy, power, authority, and status among the people in the partnership and design team. Engeström's (2008) description of three types of subject-object-subject relationships can provide a lens for viewing these challenges that arise out of joint work: coordination, cooperation, and reflective communication (Raeithel, 1983 and Bernd Fichtner, 1984 as cited in Engeström, 2008). Here, the examples are given of just two interacting people, but of course, these relationships can extend to more or all of the people in a work team. *Coordination* is when each person performs their assigned or scripted role in the activity system, each focused on their own object of activity. *Cooperation* is when both people focus together on a shared problem or joint object of activity. *Reflective communication* is an expansive type of relationship that occurs when both people re-conceptualize the ways in which they interact in relation to each other and to the shared problem or joint object of activity. I see commonalities here to Edwards' description of relational agency, which will be described in the next section.

With a CHAT perspective, the mechanisms for transitioning a relationship from coordination to cooperation to communicate is through disturbances, ruptures, and expansions, all of which occur within the zone of proximal development between activity systems (Engeström, 2008). *Disturbances* are "deviations from the normal, scripted course of events in the work process, normal being defined by plans, explicit rules, and instructions, or tacitly assumed traditions (Engeström, 2008, p. 24). Disturbances may take on many forms including disagreement, failure, or obstacles, and may arise as discursive disturbances during talk among members of a team (Engeström, 2008). Engeström (2008) identified different ways that individuals and teams manage disturbances; these include: negotiating, accepting responsibility, using authority, complaining, avoiding confrontation, engaging in open conflict, and attempting or completing an innovation. *Ruptures* are block, breaks, or gaps in understanding or in the flow of information between people in a team (Engeström, 2008). Finally, *expansions* are a "collaborative reframing of the object by moving to cooperation or communication" (Engeström, 2008, p. 51). These challenges may originate from a place of authority and status (top-down) such as issues of power in a research-practice partnership, or bubble up from within the team itself (bottom-up), as can occur when teams negotiate through design tensions (e.g., Engeström, 2008). Disturbances, ruptures, and expansions can manifest as opportunities for design innovation or as obstacles that threaten the continuation of a partnership. O'Neill (2016) issued a call for learning scientists to employ CHAT approaches to design-based research that seek to understand not just successful partnership stories, but to also share their narratives of design misadventures and partnership failures, including how partnerships "break down, fail to gel, or transform over spans of time" (p. 500). While stories of disturbances and ruptures within design-RPPs are currently rare in the literature, studies of expansions are also informative to understanding the complex work of individuals and teams within these design partnerships (e.g., Severance, Penuel, Sumner, & Leary, 2016).

The relational turn in CHAT. Cultural-historical activity theory, as described, focuses on change that occurs at the level of the activity system, however, Edwards (2005) proposes that "the individual needs to be connected analytically with the collective through micro-level analyses of the relational" (p. 6). Edwards (2005, 2011, 2012) takes a "relational turn" in CHAT analyses to understand how individuals engage in collaborative work that occurs across the boundaries of professions and practices. When people from different professions representing different institutions form a team that engages in joint work across the boundaries of practice, they can be considered as being inter-institutional, inter-professional, cross-practice collaborations (Edwards, 2012). Within these collaborations, knowledge and expertise is distributed among the members (Edwards, 2005). Whereas Vygotsky focused on an individual's sensemaking (Edwards, 2005) and Engeström (2001, 2008) focuses his analysis on the interactions between multiple activity systems, Edwards (2012) focuses on the intersection of practices between individuals. Of particular interest to Edwards is what happens when professionals move out of the protection of their home institutions, or what Sennett (1999, as cited in Edwards, 2005) calls "institutional shelters" while engaging in inter-institutional, inter-professional, cross-practice collaborations. This relational perspective on CHAT could be applied to analyzing the coordination of social practices that happen during co-design work. This analysis could focus on the individual professionals who make up the design team within a RPP who have left their institutional shelters to form a new activity system—the design team—to engage in joint work at the boundaries.

Edwards (2012) proposed three cultural-historical conceptual tools to help understand the boundary work that occurs in these complex collaborations: relational expertise, relational agency, and common knowledge. Edwards (2012) proposed that professionals working in inter-professional collaborations need to develop *relational expertise*, where they recognize and engage with the expertise of other people in the collaboration, and integrate their own knowledge with the knowledge of others. She describes this practice as "being able to work with what others offer while also making visible and accessible what matters to you" (Edwards, 2012, p. 26). Relational expertise is needed to work across the boundaries of practice and professions. It is dependent on the building of *common knowledge*, the shared understandings or knowledge that is held in common among the members of a collaborative group (Edwards, 2012). Carlile (2004 as cited in Edwards, 2012) suggests that knowledge can be mobilized across practice boundaries through three processes: transfer, translation, and transformation. When a work group develops common knowledge, transfer of ideas can happen quickly and fluidly across practice boundaries, though sometimes some translation is required. Through inter-professional collaboration, knowledge can also be transformed when professionals think radically and creatively across the boundaries of practice (Edwards, 2012). Edwards (2012) explains that relational expertise "involves building, contributing to, and working with common knowledge" (p. 26). Common knowledge mediates the third conceptual tool, *relational agency*, which is an individual's "capacity for working with others to strengthen purposeful responses to complex problems" (Edwards, 2011, p. 34) or put more simply, "drawing on the resources of others and being a resource for others" (Edwards, 2005, p. 11). Relational agency emerges through a two stage process of recognizing others' motives, perspectives, and resources and then aligning to the interpretations made by other professionals in the collaborative group. Edwards (2011, 2012) argues that joint work across practice boundaries occurs through these processes of relational engagement and responsive collaboration. I see commonalities here between Edwards' (2012) concept of relational agency and Engeström's (2008) concept of reflective communication, both which may contribute to expansive and generative forms of collaboration.

One component of common knowledge is the development of common language within a collaborative group. The development of a shared, also called a hybrid or pidgin, language is one way that groups coordinate their work together and signal an exchange occurring within the trading zone of the partnership (Penuel, Coburn, & Gallagher, 2013). These types of *hybrid languages* can include using jargon from the different institutions and disciplines in the partnership or the uptake of ideas and terms from others. For example, Penuel, Coburn, and Gallagher (2013) observed the emergence of a hybrid language in a university-school partnership when a teacher merged a conceptual model proposed by the researchers with her own knowledge of the process of scientific inquiry, and when researchers took up the use of the term "ownership" that was used frequently by teachers when discussing the purpose of their co-designed science curriculum unit. A hybrid language helps to mediate boundary talk within a cross-practice group. Edwards (2011) notes that an individual's professional multilingualism allows him or her to cross and negotiate practice boundaries.

I have traced the origination and evolution of activity theory, the development of CHAT as a way to investigate collaboration within and across groups, and the relational turn in CHAT that can provide insights into the role of individuals within these complex teams. Next, I delve into social practice theory and the ways in which it integrates emotion, motivation, and agency into the CHAT framework and considers the political and economic forces that shape people, their identities, and their practices.

Social Practice Theory. Social practice theory, which is rooted in Vygotskian and Bakhtinian cultural-historical theories and the Danish perspectives of critical psychology, was developed by social anthropologists Dorothy Holland and Jean Lave and psychologists Ole Drier and Martin Packer (Penuel, 2014; Penuel, DiGiacomo, Van Horne, & Kirshner, 2016b). Social practice theory asks, "how are lives, persons, and practices produced in ongoing everyday practice?" in particular times and at particular places that together make up the conduct of everyday life (Lave, 2012 as cited in Penuel, 2014, p. 91; Dreier, 2016). It aims to understand how people, each a *person-in-practice,* learn and become who they are in different forms of social practice across both temporal and spatial dimensions, as people chart their own interest-driven *learning pathways* (Penuel, DiGiacomo, Van Horne, & Kirshner, 2016b). In this way, learning is thought of as “the transformation of participation in practices that are themselves changing”, which involves processes of identification and becoming (Penuel, 2014, p. 91) or what Holland and Lave (2009) call *intimate* or *personal identities*.

In order to understand this learning and becoming, Penuel (2014) described three broad areas that are the focus of analysis for social practice theory: *telos*, person-world relations, and learning mechanisms. *Telos* is the direction of how learning and change emerges over time and across spaces. *Person-world relations* is how people, practices, and their world are mutually constituted. The idea is that people and practices are *mutually constitutive* in that people participate “diverse and evolving concerns” through the use of tools and identities that are available in that particular social practice, which in turn makes the person into a certain kind of person, or their *practice-linked identity* (Penuel et al., 2016b, p. 36; see also Bell, Tzou, Bricker, & Baines, 2012; Nasir & Hand, 2008; Penuel, 2014). For instance, the kind of person who is a sports fan, a bookworm, or an online gamer. These personal identities evolve by “gathering, adopting and pursuing stances” toward the things that a person is interested in, concerned about, or values (Penuel et al., 2016b). Finally, learning mechanisms are the “ways by which learning comes about” (Lave, 1996 as cited in Penuel, 2014, p. 92).

Social practice theory recognizes that social practices are not neutral or benign; they occur within institutional, cultural, and political-economic structures and struggles (Bell, Tzou, Bricker & Baines, 2012; Dreier, 2016; Holland & Lave, 2009; Penuel, 2014). Holland and

Lave's (2009) concept of *contentious local practice* captures this acknowledgement that local struggles are always part of these larger, contextual *enduring*—or historically institutionalized—*struggles*. Social practices regulate who has access to what practices, spaces, roles, and identities in the community in which it occurs, as well as through larger cultural and political contexts (Penuel, 2014). Holland and Lave (2009) capture the historicity of people and their local practices through their concept of *history-in-persons*. These issues of access in turn impact and may constrain learner's agency as they pursue their interests and the learning pathways that are available to them (Penuel et al., 2016b). Penuel (2014) proposes that ethnographic methods are a way of applying this critical lens in order to understand how people engage in social practices as they move across different settings and as they unfold over time. Therefore, when a researcher develops an account of social life through the lens of social practice theory, it is descriptive, analytical, critical, and emancipatory (Penuel, 2014).

Bell and his colleagues' (2012) cultural learning pathways theoretical framework, developed through ethnographies of youth across diverse cultural settings, specifically considers issues of human difference and inequity through a social practice lens. *Cultural learning pathways* are "connected chains of personally consequential activity and sense-making—that are temporally extended, spatially variable, and culturally diverse with respect to value systems and social practices" (Bell, Tzou, Bricker, & Baines, 2012). The theoretical framework is an application of social practice theory and an extension of Dreier's (2016) ideas about the social practices that make up the conduct of everyday life. People are thought to engage in *life-long* (a temporal dimension), *life-wide* (a spatial dimension), and *life-deep* (a value-driven dimension) learning (Banks et al., 2007 as cited in Bell, et al., 2012). The cultural learning pathways framework considers the development of interest through the emergence of situational interests and concerns, coordinated participation with others in social practices, the building of supportive social relationships, and the development of practice-linked identities (Bell et al., 2012). These learning outcomes are developed along extended pathways among connected constellations of situated events, which includes particular sociomaterial arrangements of settings, a learner's active use of discourses and stances, and social positioning that can emerge based on a learner's stance and identity and other's perceptions of them (Bell et al., 2012). Each of these dimensions can serve to support or constrain learning.

Social practice theory and cultural-historical activity theory have some similarities. Penuel and his colleagues (2016b) explain that both theories were drawn from Marx and Engel's accounts of human activity. Both theories are focused on activity and assume that people react to cultural activities (Holland & Lave, 2009). However, the unit of analysis differs in that CHAT focuses on activity systems while social practice theory focuses on the person-in-practice, history-in-persons, and their processes of learning and becoming along cultural learning pathways (Bell et al., 2012; Penuel et al., 2016b). Social practice theory also acknowledges the roles of emotion, motivation, and agency in shaping a person's personal identity and considers the political and economic forces that shape people, practices, and inequities. This includes a focus on the differences—including social constructs such as race, class, gender, and disability—and conflicts between people as they engage in social practices and how enduring struggles shape that engagement (Holland & Lave, 2009).

What does social practice theory have to offer in relation to understanding design practices, collaboration, and learning in design-RPPs? As mentioned previously, social practice theory asks "How are lives, persons, and practices produced in ongoing everyday practice?" in particular times and at particular places (Lave, 2012 as cited in Penuel, 2014, p. 91). The social practices of everyday life include the worlds of work and school (Dreier, 2016), therefore, social practice theory could be used to trace the cultural learning pathways (Bell, Tzou, Bricker, & Baines, 2012) of a teacher-designer involved in a co-design initiative across settings and time, from design meetings, to classroom enactment, to debrief and reflection sessions. A social practice lens could be helpful for understanding the learning pathways of a boundary spanner as she moves across boundaries of institutions and roles in a research-practice partnership. It provides a framework for identifying and analyzing the contentious local practices of the partnership or design team and how they are situated in historically institutionalized struggles. It also provides a lens for considering the dimensions of interest, concern, agency and motivation, as well as the emotional aspects of learning and becoming of the members of a design-RPP.

Design-based Research for Investigating Co-Design Processes

Both CHAT and social practice theory provide helpful theoretical frameworks for understanding how RPPs and design teams function (or do not function). Previously, participatory forms of design research were also presented. In this section, design-based research (DBR) is presented as a methodology for the research of co-design and partnership processes. It should be mentioned that ethnography and case study research are often used in tandem with DBR in these investigations.

Design-based research (DBR) is a methodology commonly used for studying collaboration, learning, and design within RPPs. DBR was initially developed by Brown (1992) and Collins (1992 as cited in The DBR Collaborative, 2003). For Brown (1992), *design experiments* were a way to move away from studying subjects in laboratories and toward studying the design of student learning “in the blooming, buzzing confusion of inner-city classrooms” (p. 141). However, Bell, Hoadley, and Linn (2004) note that DBR can be traced back to over a century ago to Dewey's approach to studying educational interventions. DBR is part of a larger methodological family known as education design research (Plomp, 2013). In DBR, researchers and practitioners partner to design, enact, and redesign educational interventions (i.e., curriculum unit, educational software) in iterative cycles that take place in authentic and naturalistic settings; however, unlike much of education design research, DBR explicitly focuses on the empirical research of the design and enactment processes. As Bell (2004) writes, this "'theory work' is a defining feature" of DBR (p. 245). As a methodology, DBR can be employed within and across various theoretical perspectives. DBR is a flexible methodology often used with sociocultural and cultural-historical theories of learning.

Qualitative, quantitative, and mixed methods approaches are all used in DBR studies. In studies of design-RPPs, data collection methods may include, as examples, observations, ethnographic field noting, interviews, artifacts, and surveys. *Conjecture mapping* (Sandoval, 2014) is a technique created specifically for educational design research. It is used for "specifying theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes" (Sandoval, 2014, p. 19). Conjecture mapping is a means for identifying high-level conjectures about how to support learning in a specific context and predicting how they will function (through embodiment and mediating processes) to produce the desired outcomes in a way that can then be empirically tested. This process "can lead to both refinements of a particular design as well as refinements of a theoretical perspective" (Sandoval, 2004 as cited in Sandoval, 2014, p. 21).

Co-design is a signature practice of education design research, including DBR. Empirical studies of design-RPPs can be focused on different scales: the interacting activity systems of a multi-tiered partnership; the collaborative tools and social practices that emerge among members of the design team; or the negotiation of design tensions of a curriculum unit or teacher and student learning during its classroom enactment. DBR can be employed to generate design principles and theories of learning, to design educational interventions, and to broadly diffuse these interventions by bringing them to scale (Bell, 2004).

The design knowledge that is developed through design-based research studies is often communicated through design narratives, design patterns, design principles, and design artifacts (Bell, Hoadley, & Linn, 2004; The Design-Based Research Collective, 2003). Design narratives are rich descriptions of the context, tools, activities, practices, assessments, and outcomes of DBR studies (Bell, Hoadley, & Linn, 2004). These narratives capture the stories of a design team and the evolution of designed products. These narratives may become even more illustrative when paired with the lens of articulation of project work (Strauss, 1988), which seeks to understand the properties, organizational processes, interactional processes, work processes, and tasks of project work. With this lens, there is an appreciation of the narrative histories and temporality of collaborative project work as they develop and change over time (Strauss, 1988). Design patterns are descriptions of “how a designed innovation interacts with settings and evolves” (The Design-Based Research Collective, 2003). Design principles, a type of analytical generalization, are often produced in DBR studies to describe the “substantive ‘what’ and the methodological ‘how’ of the intervention” that may be helpful for researchers working in other contexts (van den Akker, 2013, p. 67). The products of the design work (e.g., curriculum, templates, and computer programs) are also a result of DBR approaches, but it should be noted that models and theories of learning, rather than products, are the priority (The Design-Based Research Collective, 2003).

The Research Agenda: Co-design of Curriculum

In their review of empirical research on RPPs in education, which they categorize as sparse, Coburn and Penuel (2016) found that most existing research has focused on the dynamics and outcomes of the partnership work. Studies of partnership dynamics tended to focus on the challenges faces by the partnership, rather than understanding how those challenges were negotiated. Studies of the outcomes of RPPs focused mostly on the implementation of a designed intervention and changes in student learning, rather than the outcomes, value, or influence of the partnership itself (Coburn & Penuel, 2016). Moreover, these researchers found that studies tended to focus on either outcomes or dynamics, but rarely on both, providing "little insight into the mechanisms by which RPPs foster the full range of intended and unintended outcomes" (Penuel & Coburn, 2016, p. 51). O'Neill (2016) called for learning scientists to not just report on success stories, but to engage in "deeply understanding how designs and design partnerships break down, fail to gel, or transform over spans of time" (p. 500). The field can learn from reports of "failed designs and misadventures" (O'Neill, 2016, p. 500; e.g., Carlone & Webb, 2006). There is a need to study the ways in which partnership challenges in RPPs are navigated successfully and not, and how design tensions during co-design work are negotiated among members of the design team.

Co-design is an approach to developing high-quality subject matter curriculum materials through participatory design processes that can engage researchers, teachers, and disciplinary experts in both design and research efforts. Co-design requires the coordination of multiple social practices within a university-school partnership both spatially and temporally. CHAT provides a helpful theoretical framework for examining design, collaboration, and learning in the culturally diverse groups that make up the interconnected activity systems of a design-RPP. Social practice theory provides a theoretical lens for understanding individuals' experiences as they engage in cross-practice design work within a design-RPP. Through these sociocultural and situate perspectives on workplace learning and everyday practice, concepts of learning, becoming, agency, identity, collaboration, tension, and boundary crossing can be explored.

Design-based research is the appropriate methodology for approaching the design and research aspects of co-design initiatives. There is need to study both the dynamics and outcomes of design-RPPs using DBR. Future studies should investigate the dynamics of the partnership and the design team, while also studying outcomes related to teacher learning and professional practice through their participation in co-design. In addition, outcomes related to student learning and experiences with the designed curriculum artifacts should be studied. Published studies of design-RPPs should not just report success stories; learning scientists have much to learn from narratives of tensions, misadventures, and failures in this complex joint work. Design narratives hold promise as communicative strategy to share narratives of design communities engaged in this complex, partnership-driven work.

Part III: Teacher Learning through Engagement in Co-design Initiatives

Teachers are increasingly participating in collaborative curriculum design initiatives, which are often viewed as an opportunity for teacher professional learning. However, as Voogt and her colleagues (2015) point out, there is a gap in the literature around understanding what contextual factors, structures, and relationships influence teacher learning through participation in co-design projects. Assumptions around what and how teachers learn through engaging in co-design, the benefits of being part of a design community, and how teachers as designers may create better curricula are all areas in need of further research. The focus of this section is on exploring literature related to teacher learning through engagement in design work in a design community. However, given the limited research base on teacher learning within the specific structure of design-RPPs, I have integrated research related to these other contexts for curriculum design that engage teachers as designers. Similarly, I have expanded upon the conception of curriculum design to include the reflexive enactment and adaptation of curriculum materials when done so as part of iterative design work.

Teachers as Designers

Teaching is a specific type of creative design work. Brown (2009) uses the analogy of jazz musicians, imagining the different variations that occur when Duke Ellington and Ella Fitzgerald each perform the same song, engaging in creative work as they perceive, interpret, plan, and perform their own renditions. This analogy applies to teachers' different interpretations and enactments of curriculum materials. Brown (2009) writes that "in both cases, practitioners bring to life the composer's initial concept through a process of interpretation and adaptation, with results that may vary significantly while bearing certain core similarities" (p. 17). He continues, "no two renditions of practice are exactly alike" (Brown, 2009, p. 17). Different variations on this idea of teachers as designers have recently emerged, including the conceptions of teacher as makers and hacker (Baker-Doyle, 2017) given the creative work involved in designing, planning, and adapting instruction.

I take up this idea of teacher as designer. However, focusing specifically on co-design initiatives, I acknowledge that teachers take on particular design roles as members of design communities and deliberately engage in particular forms of design practices that are different from the everyday instructional design of the classroom teacher. This type of design is design for others, not just design for self and for one's own classroom use. It is the design of interventions in response to broadly applicable opportunities of practice, such as the current wave of K-12 science curriculum design in response to the release of the *Next Generation Science Standards* (NGSS Lead States, 2013). This approach requires that teacher-designers develop specialized forms of design knowledge and practices. Rather than fostering pedagogical design capacity (Brown, 2009) or instructional planning competencies (Voogt et al., 2015), instead, involvement in co-design initiatives requires that these teacher-designers develop specific forms of design expertise (Huizinga, Handelzalts, Nieveen, & Voogt, 2014).

This section begins by acknowledging the current climate of reform-oriented science curriculum design and then highlights what makes design-RPPs interesting contexts for teacher learning. I then describe research related to the teacher-curriculum material relationship, including what and how teachers learn through the *use* of educative curriculum materials. I then synthesize literature related to teacher learning through the *design*, *adaptation*, *enactment*, and reflective *revision* of curricula, practices which are commonly employed in co-design initiatives. Four frameworks for teacher professional learning are presented, each offering different conceptual and descriptive understandings of the factors that influence teacher learning through the process of co-design. I conclude by surfacing major gaps in the literature as opportunities for future research.

The Current Climate of Reform-oriented Science Curriculum Design

Curriculum materials are often the tool employed by reform-oriented policymakers with the goal of influencing instruction (Brown, 2009). Indeed, in the reform-oriented culture of contemporary science education, there is currently a great need for high-quality science curriculum materials that are designed for (or “aligned to”) the Next Generation Science Standards. Since the publication of the new standards in 2013, commercial publishers of K-12 curriculum materials have been engaged in developing and publishing materials purported to be aligned to the NGSS. Achieve, the leading non-profit organization supporting the implementation of the new vision for science education, has recently developed tools, metrics, and processes for the review and approval of new science curriculum materials, such as the EQuIP Rubric and the NGSS Badge, to ensure that these materials are in actuality deeply-aligned to the NGSS. As these curriculum materials have become available, districts around the country have begun (sometimes controversial) large-scale curriculum adoptions, in which a district chooses and licenses commercially available science curriculum materials from a publisher. During the roll-out of these common materials, teachers are typically provided with professional development and then expected to enact the materials in their classrooms, often with a high level of fidelity.

Design-RPPs focused on K-12 science and engineering education are situated in this current climate of curriculum-based reform, offering an alternative path for the design or adaption of curriculum materials that is responsive to community, school, and student needs. Moreover, Voogt and her colleagues (2015) reflect that teachers are increasingly becoming involved in reform-oriented co-design initiatives, with the assumption that engagement in co-design provides a context for teacher learning and professional development.

What Makes Design-RPPs Different as Contexts for Teacher Learning?

A design-RPP may function as a type of professional learning community where the ultimate focus resides with the design of a curriculum artifact or innovation, shifts in teacher learning and practice, and improvements in student achievement, with design work functioning as the mediating practice. Therefore, teacher involvement in design-RPPs, where teacher learning is centered in practice, can be investigated as an alternative, practice-oriented approach to professional learning communities and other more traditional forms of professional development. However, questions remain about what forms of expertise might teachers developed as they participate in this kind of work, resulting shifts in teacher practice, as well as the affordances and challenges to teacher learning that arise in this type of design work.

The difficulty for researchers is that design-RPPs are different than more traditional settings for teacher learning; therefore, theories and conceptual frameworks of teacher professional learning do not necessarily apply. For example, McDonald, Kazemi, and Kavanagh (2013) proposed a cycle for pre-service teacher professional learning that included representations of practice (i.e., learning about the activity), approximations of practice (i.e., preparing for and rehearsing the activity), classroom enactments (i.e., implementing activity with students), and investigations of practice (i.e., reflecting on the enactment). As applied to the activities of a design-RPP, creative design work occurs somewhere between representations and approximations of practice, with mini cycles of iterative design and redesign causing oscillations between classroom enactments and investigations of practice. The authors explain that these four activities can take place across controlled, designed, and authentic settings. However, when teacher professional learning occurs through co-design activities within the context of a design-RPP, the structures and supports provided by the partnership form a different kind of context, what I call a *designer context* in which teachers assume the role of designers within a design community of others. As described in Parts I and II of this chapter, design-RPPs are different than more traditional school-based forms of professional learning. In some ways, a design-RPP may function like a professional learning community, in other ways more like a work group or research study.

In the following sections I will discuss how teachers learn through participation in the *use, collaborative (re)design*, *adaptation*, and *enactment* of curricula, with a focus on teacher learning through design activities. Since the literature base on teacher learning within the context of design-RPPs is limited, I will expand my inquiry to teacher learning and curriculum design literature more broadly.

The Teacher-Curriculum Relationship

It is helpful to begin by considering how teachers interact with tools like curriculum materials and what they learn through this process. An exhaustive review of the literature on teacher's use of curriculum is beyond the scope of this chapter, therefore I highlight several sociocultural perspectives on tool use and conceptual frameworks for thinking about the teacher-tool relationship. With this perspective, curriculum materials are considered to be culturally rooted artifacts or tools of representation, communication, planning, and instruction as well as an organizer of classroom activity (Brown, 2009; Russ, Sherin, & Sherin, 2016). Curriculum as tools can take on many forms, including written or digital curriculum documents, textbooks, pacing guides, laboratory manuals, educational software, state and national standard documents, and assessments of learning (Russ, Sherin, & Sherin, 2016). This view of tools as mediators of activity and learning are grounded in the writings of Vygotsky, Wartofsky, and Wertsch (Vygotsky 1978; Wartofsky, 1973; Wertsch, 1991, 1998; all as cited in Brown, 2009). In this view, humans and artifacts (tools) cannot be separated, as the tools mediate human activity in ways that both afford and constrain activity and learning. Brown (2009) uses Wertsch's (1998 as cited in Brown, 2009) concept of the outlooks of "half-full" (affordances) and "half-empty" (constraints, not thought of as acting as a hindrance) to understand how curriculum materials mediate teacher and student activity. With the "half-full" outlook, the materials are enablers of activity that signal its intended use, while the "half-empty" outlook considers the ways that the materials constrain activity by helping to "provide meaning and coherence within an otherwise enormous range of instructional possibilities" (Brown, 2009, p. 21). Across disciplines, educational researchers have investigated how teachers interact with and use curriculum materials. For example, within mathematics education, Stein, Remillard, and Smith (2007) differentiate between the written curriculum (as written by its authors), intended curriculum (as interpreted by the teacher and conceived of in the teacher's instructional plan), and enacted curriculum (as actually implemented in the classroom), explaining that many factors may influence the transformations between them, including a teacher's professional identity and professional communities. These authors suggest that teachers have three stances on their use of curriculum: curriculum use as following or subverting; curriculum use as interpreting; or curriculum use as participating with the curriculum materials (Stein, Remillard, & Smith (2007).

Teachers' use of curriculum can be thought of as bidirectional, relational, context-dependent, and socially-influenced. Brown (2009) points out the *bi-directional* influences of the teacher-tool relationship, as the curriculum influences the teacher through its affordances and constraints, while at the same time the teacher leverages curriculum resources through his or her own perceptions and decisions. Lloyd, Remillard, and Herbel-Eisenmann (2009) assert that teachers' use of curriculum materials is *relational*, with the teacher "entering into a relationship with the material's designer" as they interpret and improvise on the material (p. 9). In the teacher-curriculum material relationship, the curriculum is a representation of the designer's ideas, intents, and values, a mediator of interaction between the designer's ideas and the teacher's perceptions and interpretations, and the tool that the teacher uses in the role of mediating subject-matter content, classroom activities, and students; this makes the teacher the "critical link" between the written, intended, enacted, and attained curriculum (Brown, 2009; Davis, Palinscar, Smith, Arias, & Kademian, 2017; Lloyd, Remillard, & Herbel-Eisenmann, 2009; cf. van den Akker, 2013). A teacher's use of tools is also *context-dependent*, with each context rich with many cultural, social, and historical dimensions. The curricular context of tool use is the "complex and layered context in which curriculum material use occurs" (Lloyd, Remillard, & Herbel-Eisenmann, 2009, p. 10). Additionally, a teachers' social network and participation in communities of practice can influence teachers' use of curriculum materials in *socially-influenced* ways. Baker-Doyle (2011) reviewed research on the relationships between teachers' social networks and their use of curriculum.

Teacher's Use of Curriculum as Educative

It is important to understand how teachers use curriculum materials in general, as it relates to how teachers use curricula that they co-authored as part of a collaborative design project, such as a design-RPP. Here, I differentiate between the *use* and the *design* of curriculum materials, although the cited authors often use the term "design" in their descriptions and analyses of curriculum use. Teachers learn as they plan their lessons and use curriculum materials, leveraging both specialized and everyday knowledge and practice to engage in this work (Russ, Sherin, & Sherin, 2016), however, lesson planning is not design work in the way that I use the term.

Inquiry into teacher's use of curriculum began in the mid-1970s with a focus on textbooks (Lloyd, Remillard, & Herbel-Eisenmann, 2009). Lloyd, Remillard, and Herbel-Eisenmann (2009) define teachers' use of curriculum materials as "a variety of pedagogical activities" which includes how they "engage or interact" with the materials, "the extent to which they rely on them" during planning and instruction, and "the role the resources play in teachers' practice” (p. 7). Brown (2009) outlines the process by which teachers interact with curriculum materials in the teacher-tool relationship as: *selection, interpretation, reconciliation, accommodation, and modification* (modifications can include the actions of adding, modifying, or omitting). Brown (2009) notes that these steps of curriculum use are the activities in which designers—in the broadest sense—engage. This process of curriculum use may be influenced by the local context as well as teachers’ creative abilities (Brown, 2009). In their review of mathematics curricula, Stein, Remillard, and Smith (2007) examined factors that influenced the transformations of instructional materials from written to intended to enacted curriculum, and what those transformations meant for student learning. These factors include the teacher (e.g., their beliefs and knowledge, orientations and stances, and professional identity), the students (e.g., teachers’ perceptions of students’ abilities, level of student choice), the teaching context (e.g., time, local cultures, teacher support, policies), and the curriculum (e.g., standards-based, conventional, educative, content, sequencing) (Stein, Remillard, & Smith, 2007).

Curriculum materials in themselves are often designed to be *educative*, with the idea that specific features of design can make using the material a source of teacher learning in addition to student learning (Davis & Krajcik, 2005; Davis, Palincsar, Smith, Arias, & Kademian, 2017). Drawing on the literature base of teacher learning in general, Ball and Cohen (1996, as cited in Davis & Krajcik, 2005) proposed five roles that educative curriculum materials might have in teacher learning. These roles include that educative curriculum materials could: help teachers anticipate and understand students’ ideas and answers elicited during instructional activities; support the teacher’s development of subject matter knowledge; help teachers situate the unit in their overall class curriculum; make the designer’s rationale visible; and promote teachers’ development of pedagogical design capacity (Ball and Cohen, 1996, as cited in Davis & Krajcik, 2005). In these ways, Davis and Krajcik (2005) assert that educative curriculum materials may help teachers develop their repertoires of practice, integrate and apply their knowledge, and enculturate teachers in professional norms, all while situated in the practice of teaching. In their review of the literature, Davis and colleagues (2017) found that "educative curriculum materials can support positive outcomes across subject areas, grade levels, and contexts," including supporting teacher learning and changing their practice (p. 294). However, more empirical research on teacher learning through the use of educative curriculum materials is needed.

Teacher Learning through Participation in Collaborative Design of Curriculum Materials

We know that teachers learn through the *use* of curriculum materials. Next I consider how teachers might learn when they are engaged in the collaborative *design* of curriculum materials. However, it must be pointed out that the research base on teacher learning through co-design is underdeveloped, signaling an opportunity for further investigation. There are many opportunities to investigate teacher learning through co-design, such as in the context of design-RPPs, but the research community has yet to thoroughly explore this research thread.

Some research studies that relate to teacher learning through co-design have investigated factors related to learning, including: teacher agency (Severence, Penuel, & Leary, 2016; Voogt et al., 2015; cf Velthuis, Fisser, & Pieters, 2015); a sense of ownership over curricular innovations (Binkhorst, Handelzalts, & van Joolingen, 2015; Huizinga et al., 2014; Voogt et al., 2015); and a deepening of reflexive practices, broadening of teachers' perspectives, and changes in their confidence and beliefs about teaching (Voogt et al., 2011). Others have examined the practices, supports, and tools of collaborative design, such as the development of boundary practices between researchers and teachers (Penuel, Allen, Coburn, & Farrell, 2015) and the use of tools or boundary objects in co-design (Huizinga et al., 2014; Penuel, Coburn, & Gallagher, 2013; Severance, Penuel, Sumner, & Leary, 2016). Additionally, researchers have investigated elements of the design community within TDT or RPP structures, such as the role of the design community's facilitator (Huizinga et al., 2014), collaboration with experts outside of the school building (Voogt et al., 2015), and the support offered by the design community as a form of social network (Penuel, Bell, Bevan, Buffington, & Falk, 2016). Finally, research has also been conducted on the types of teacher knowledge that are affected by participation in co-design, such as subject matter knowledge, pedagogical content knowledge, curriculum consistency expertise, and the development of curriculum design expertise (Huizinga et al., 2014). In addition, it is not just teachers who may benefit from their participation in co-design initiatives; researchers, experts, and other co-design partners may benefit from partnering with teacher-designers in the joint work of co-design, another area that needs further investigation (The Design-based Research Collective, 2003). In the following sections, I further expand upon examples of research findings related to teacher agency, curriculum design expertise, and professional communities of practice.

Teacher agency. Some researchers have examined teachers' sense of agency through participation in co-design activities. Severance, Penuel, Sumner, and Leary (2016) used cultural-historical activity theory (CHAT) as both theory and methodology to guide their study of teacher agency in the Inquiry Hub design-RPP. This large partnership involved 16 secondary science teachers, along with district administrators, community stakeholders, curriculum writers, disciplinary experts, and educational researchers. Their collective goal was two-fold: the design of a new science unit designed with NGSS and a structured opportunity for teacher learning through curriculum co-design. The design community was specifically organized and structured by the researchers "to promote teacher agency using specific tools, routines, and structures"

(Severance et al., 2016, p. 544). In their analysis, the researchers found that teachers' agency in the design community allowed for changes to both the designed product—the curriculum unit—and the design process itself. While the researchers did not study processes of learning and change at the level of the individual participating teachers, their findings of collective learning of the group as a whole inform how collaborative design communities can be organized and structured so that teachers can act as agents of change through design. Voogt and her colleagues (2015) in their study of three cases of Teacher Design Teams in three African countries, Canada, and the U.S. found that teachers' involvement in co-design had an effect on individual teacher agency. In the case of the African and American TDTS, a sense of agency was realized through teachers' involvement in identifying the opportunity of practice and designing the innovation (Voogt et al., 2015).

Curriculum design expertise. Another area of research has been focused on the types of design expertise needed to engage in the design of curriculum materials. Curriculum designers, including teacher-designers, may need to develop two types of specialized design expertise: generic design and process expertise and specific design expertise (Huizinga, 2009 as cited in Huizinga et al., 2014*). Generic design and process expertise* is defined as "knowledge and skills for enacting design processes in general" while *specific design expertise* is defined as "knowledge and skills required for developing curricula" (Huizinga et al., 2014, p. 36). Specific design expertise consists of four types of knowledge and skills: curriculum design expertise, curriculum consistency expertise, as well as subject matter knowledge and pedagogical content knowledge as applied to curriculum design, and knowledge of the reform or problem of practice for which the innovation is needed (Huizinga et al., 2014). *Curriculum design expertise* is defined as "the knowledge and skills to enact curriculum design" (Huizinga et al., 2014, p. 36).

This concept has also been called *curriculum design competencies*, *instructional design competencies*, and *design expertise* by other researchers, as cited by Huizinga and his colleagues (2014). For teachers, curriculum design expertise includes the knowledge and skills needed to: formulate a problem statement; generate ideas; systematically design curriculum; develop formative and summative assessments; engage in curricular decision-making; and implement management skills (Huizinga et al., 2014). *Curriculum consistency expertise* has to do with the internal consistency of the curriculum, which refers to the balance, coherence, and alignment of the curriculum with its larger context (van den Akker, 2003 as cited in Huizinga et al., 2014), as well as the external consistency of the curriculum, which refers to the perceptions of teachers and stakeholders (Kessels, 1999 as cited in Huizinga et al., 2014). A practice-based view of teaching pushes us to think beyond design expertise solely in the cognitive perspective, as knowledge held in the mind of an individual. Rather, design expertise is distributed among the participants in the design community so that teacher learning of design practices develops *through* the practice of design. Teachers learn design by doing design, as supported by scaffolds and mediated by the use of tools (such as organizing frameworks, collaborative documents, and lesson plan templates).

Professional communities of practice. The partnership activities within a design-RPP form a new kind of professional community of practice for the participating teachers. We know that effective professional learning communities (PLCs) or Communities of Practice (CoPs) can offer a context for teacher learning (e.g., Little, 2002, 2003; National Academies of Sciences, Engineering, & Medicine, 2015). Some researchers have investigated how membership in a professional community of practice affects teachers. Davis, Petish, and Smithey (2006), writing about teachers' communities of practice in general, note the value of collegial relationships and community membership in helping novice teachers develop their senses of professionalism and belonging. However, as Little (2002) has pointed out, the literature base is underdeveloped around our understanding of the “specific interactions and dynamics” by which these communities offer intellectual, social, and material resources for teacher learning (p. 917) and the trajectories of development that occur among the members of the community as their participation and professional practices change over time and across activities and settings (see also “transformation of participation” in Rogoff, 1997). Moreover, the research base is thin on investigating teacher professional learning through co-design in a community of practice (Voogt et al., 2015) and in particular, within the context of design-RPPs. I summarize some of these more salient lines of inquiry below related to teacher learning through community.

Repertoires of practice for collaboration. How do people from different professions representing different institutions form a team and productively engage in collaborative work? These types of inter-institutional, inter-professional, cross-practice collaborations are a hallmark of design-RPPs within which knowledge and expertise is distributed among the members (Edwards, 2005, 2012). Edwards’ (2005, 2001, 2012) cultural-historical conceptual tools of relational expertise, relational agency, common knowledge, and professional multilingualism can be helpful for understanding the conditions that support teachers’ participation in expansive and generative forms of cross-practice collaborations. The development of repertoires of practice for collaboration is a type of professional expertise that may be helpful for teachers to develop in order to engage in these types of collaborations.

Horizon of observation. How might participation in a design community shift or expand what perspectives, tools, discourses, and practices are available to teachers? Hutchins’ (1993, 1995) concept of the horizon of observation captures this idea. An individual is limited by their horizon of observation of what they are “able to see, hear, and participate in” within their work environment; for teachers in particular who work within siloed disciplines and often behind closed classroom doors, the insularity of their work environment can restrict their horizon of observation (Little, 2003). This limitation on the available professional learning environment might be expanded through participation in a design-RPP, in which teachers may collaborate with teachers from other departments, schools, or districts while also forming collegial relationships with disciplinary experts and educational researchers.

Social networks of design communities. Might a design-RPP also function as a type of social network for teachers? Voogt and her colleagues (2015) noticed this in their study of eight teachers who participated in researcher-led virtual co-design workshops over a six-week period. Though they had never met in person, the teachers felt that the community served as a support system, or what Baker-Doyle (2011) calls an “advice network”. Over time, these teachers began to turn to each other for advice and assume leadership responsibilities for their joint work, allowing the researcher to step back as the sense of professional community grew. For early-career teachers in particular who are building their professional social networks, participation in a design-RPP may offer support and learning opportunities. However, the research on this the value of design communities as social networks currently is thin.

Supports offered through community. What kinds of supports can the design community offer to teachers? In their small-scale qualitative study of TDTs in the Netherlands, Huizinga and his colleagues (2014) conducted interviews with a purposeful sample of six teachers and six facilitators of TDTs to better understand the problems encountered by teacher-designers and the types of design supports offered to them. They found three areas in which the teacher-designers needed support during all stages of the curriculum design process: curriculum design expertise, pedagogical content knowledge for new instructional practices, and curricular consistency expertise. As a result, Huizinga and his colleagues (2014) suggest that in order to best support teacher-designers involved in the collaborative design of lesson series, support should be embedded and offered just-in-time to increase opportunities for teacher learning and that tools (such as lesson templates, curriculum frameworks, and peer-evaluation guides) should be leveraged or designed, as needed, to support quality design work.

This section synthesized some of the literature on what and how teachers may learn when they engage in collaborative design work within a design-RPP. The following section focuses on the next phase of design work, when the partner teachers within a design-RPP engage in adaptations of the designed curriculum materials for initial enactment in their own classrooms. During these micro-cycles of design-test-redesign, what do teachers learn when they enact and adapt curriculum?

Teacher Learning through Enactment & Adaptation

Shulman (1990 as cited in Russ, Sherin, & Sherin, 2016) wrote that "the essential value of curriculum is how it permits teachers to adapt, invent, and transform as they confront the realities of classroom life" (p. 420). We know some about the teacher-tool relationship (e.g., Brown, 2009), how teachers use curriculum materials (e.g., Brown, 2009), how they learn from educative materials (e.g., Davis & Krajcik, 2005), and how they adapt instruction (e.g., Parsons et al., 2018). However, the research base is underdeveloped when it comes to examining how teachers learn through the process of adaptation and enactment of curriculum materials as part of the co-design process in design-RPPs. What benefits might exist for teachers as they engage in this collaborative design work and enact a new curriculum in their own classrooms? What kinds of structures and supports could be introduced to support teacher learning during these processes of enactment and adaptation? How might teachers learn to reflexively adapt curriculum during enactment, in order to inform iterative revisions to the curriculum as a design artifact? In what ways is the piloting of newly designed curriculum from a design-RPP different from other forms of curriculum implementation? How might the iterative cycles of design used in design-based research support teacher learning? I begin with examining different types of adaptations made by teachers.

Adaptive teaching. Teachers engage in adaptations when they make changes to a written curriculum for enactment in their own classes, and through the moment by moment decisions made during instruction. When teachers facilitate learning, some teachers may be able to engage in a process of adaptive teaching, in which they make both large and small instructional adaptations, as these kind of teachers possess pedagogical content knowledge “that is flexibly and innovatively employed” (Parsons et al., 2018, p. 207). In a review of empirical studies on adaptive teaching ranging from 1975-2014, Parsons and his colleagues (2018) describe adaptive teaching as a gold standard for the teaching profession. Parsons and his colleagues’ (2018) extensive literature review found that adaption in the classroom was motivated by student learning, understanding, interest, motivation, or behavior. However, their research synthesis was focused on instructional adaptations writ large rather than being specifically focused on how teachers adapt curriculum materials. Knowing how and why teachers adapt curriculum materials as they plan for and engage in instruction is helpful for understanding how adaptation will likely occur during the enactment of newly designed curricula within a design-RPP. As Shulman described, curriculum materials are meant to be adapted and transformed through the negotiations between the teacher, the students, the curriculum materials, and the context.

Perspectives of curriculum adaptation. When teachers enact a curriculum in the classroom, they may interact with the curriculum-as-written in different ways. Two divergent perspectives on curriculum adaption during enactment are the fidelity perspective and the participatory (Penuel & Gallagher, 2009) or enactment perspective (van den Akker, 2013) which focuses on local adaptation.

The fidelity perspective. A *fidelity perspective* focuses on how well a teacher implements a curriculum with fidelity as written, as compared to the intentions of the curriculum designers (Penuel & Gallagher, 2009). This perspective is in alignment with Stein, Remillard, and Smith's (2007) concept of teachers' use of curriculum as following or subverting. This perspective is also aligned with ideas about creating prescriptive "teacher-proof" curricula that were popular during the rise of high-stakes testing (Parsons et al., 2018) and that continue to arise during large-scale curriculum adoptions. Currently, equity arguments are often made by district curriculum offices in favor of teaching a guaranteed and viable curriculum with fidelity, in which all students across a district receive the same standards-aligned curriculum. However, enacting a curriculum with fidelity strips a teacher of creativity and agency over her instruction and classroom practice and does not allow for adaptations in response to teacher or student interests and areas of expertise.

The participatory perspective. In *The Reflective Practitioner*, Schön (1983) painted a bleak picture of the bureaucratic "system of controls" that dictated urban public schools at the time, questioning what would happen if instead teachers had "the freedom to reflect, invent, and differentiate" and had agency over the curriculum. This kind of *participatory perspective* on curriculum adaptation views the enactment of curricula as a relationship between the curriculum materials, the teacher, the students, and the local context (Barab & Leuhmann, 2003; Penuel & Gallagher, 2009). With this participatory perspective, teachers engage in the practice of *local* *adaptation* recognizing that curriculum materials are co-constructed and socially derived, and when implemented, “become assimilated as part of the cultural systems in which they are being realized” (Barab & Luehmann, 2003). Similarly, Schön (1983) described the lesson plan as “a skeleton around which the teacher develops variations according to her on-the-spot understanding of the problems of particular students” (p. 333). This participatory perspective is in alignment with Stein, Remillard, and Smith’s (2007) conception of teachers’ use of curriculum as interpreting or participating with the curriculum materials.

It must be noted that there are many competing tensions when teachers engage in curriculum adaptation to meet their desired learning goals for students. As noted previously, Brown (2009) described a process of curriculum use in which teachers select, interpret, reconcile, accommodate, and modify curriculum materials. In this process, they are balancing competing needs as they adapt the curriculum based on their goals for student learning, the constraints of their setting, and the “talents, interests, experiences, and limitations of their students (Brown, 2009). Teachers may add, modify, or omit parts of curriculum materials (Brown, 2009). Productive adaptations rely on reflexive enactments of the curriculum materials.

Reflexive adaptation and enactment. Parsons and his colleagues (2018) describe adaptive instruction as socially constructed and intertwined with a teacher’s practices of metacognition and reflection before, during, and after classroom instruction. It is the reflexive enactment and adaptation of designed curriculum materials that informs the design-based research approach to curriculum design. Schön’s (1983) concept of a reflective practitioner is often quoted in the educational research and is relevant to this discussion. When teachers engage in reflection-in-action during and reflection-on-action after their adaptation and enactment of designed curriculum materials, they can actively contribute their reflections and experiences back to the design community to inform the next iterative cycle of redesign. Design-RPPs take up this participatory perspective on curriculum adaptation, in which intentional structures may support teacher learning through such adaptations, such as when a researcher joins the teacher in the classroom as a co-teacher during enactment or engages in daily debrief sessions with teachers during the enactment of a unit. However, there is much opportunity for the research community to study these types of social practices and supports within design-RPPs.

Conceptual Frameworks for Studying Teacher Learning through Co-design

Researchers have developed a number of conceptual frameworks to consider different aspects of teacher learning through their engagement in curriculum design. In this section, four frameworks are described that are relevant to this discussion and hold promise for researchers investigating co-design within design-RPPs. Criticisms and suggestions for developing models specific to design-RPPs are also provided. First, Brown's (2009) Design Capacity for Enactment Framework describes the pathways taken by teachers as they enact curriculum materials in their classrooms, including the design decisions they make when planning and facilitating instruction that relates to the degree to which the teacher implements the curriculum with fidelity or engages in adaptations. However, this model focuses on the cognitive resources and decision-making processes of the teacher without contextualizing against social, cultural, and institutional factors. Second, Clarke and Hollingsworth's (2002) Interconnected Model of Professional Growth was developed to capture teacher change through professional learning and growth, which can be viewed though both cognitive and situative lenses as the development of knowledge or the development of practice. This framework affords a perspective along four domains of the change environment, complicating a view of how teacher learning might unfold during design work. Third, Engeström's (2001) concept of expansive learning is informed by cultural-historical learning theory and was developed to describe cycles of learning that unfold in workplaces, without a specific focus on teachers. Expansive learning occurs at times in which "we must learn new forms of activity which are not yet there" at times when learning occurs horizontally, in the absence of an expert who already possesses the required knowledge (Engeström, 2001, p. 138). Within a design-RPP, the researchers and teachers each hold specific forms of expertise, but none of them enter into the design community with all the answers in a context in which the questions continue to surface and unfold. This framework affords a way of thinking about the horizontal learning that occurs among the members of a design community in which content, expertise, and tools are developed and learned together. Lastly, Binkhorst, Handelzalts, Poortman, and van Joolingen (2015) developed the Integrated Descriptive Framework for TDTs to describe the inputs, process, and outcomes involved in collaborative curriculum design within the structure of Teacher Design Teams (TDTs) in the Netherlands. This framework provides a tool for researchers to consider the activities, interactions, and organizational factors that influence teacher learning when they engage in collaborative curriculum design. Each of these four frameworks provide insights into our understanding of teacher learning through co-design, but all of these frameworks have limitations. It must be pointed out that none of these frameworks were developed from empirical studies of teacher learning within design-RPP settings, therefore it is an extrapolation to apply them to this context. However, in the absence of conceptual frameworks specific to teacher learning through co-design in design-RPP contexts, these models are a potential starting place for developing new understandings. Each of the four frameworks is described below.

Framework #1: Design Capacity for Enactment Framework. As they use curriculum materials, teachers engage in processes of artifact appropriation. Brown (2009) describes this as the ways in which teachers engage in “design-based decision-making” (Edelson, 2002 as cited in Brown, 2009) which “results in differential distribution of agency across the teacher and the instructional resources” (Brown, 2009, p. 25). Brown describes these degrees of artifact appropriation as offloading, improvising, and adapting. When a teacher *offloads*, he or she is relying on a curriculum resource mostly as written, offloading “a large degree of agency for guiding instructional activity onto the materials” (Brown, 2009, p. 24). When the teacher *improvises*, he or she goes off script, employing their own instructional practices with “minimal reliance on the materials” so that the instructional agency shifts mainly to the teacher. (Brown, 2009, p. 24). Finally, when the teacher *adapts*, he or she is working somewhere in between, relying on both the curricular resources and their own professional resources to plan and enact instruction, so that the agency is shared between teacher and tool.

Brown’s (2002, as cited in Brown, 2009) Design Capacity for Enactment Framework (DCE) is a conceptual framework to help researchers analyze and understand the multiple pathways that teachers take in the teacher-curriculum material relationship. Each teacher forges their own path in their decisions to offload, improvise, and adapt as they use curriculum materials, analogous to jazz musicians performing their own interpretations of the same composition. Teachers bring their personal and professional resources to the teacher-tool relationship, while the curriculum material presents the “core ideas, activities undertaken to explore them, and the objects that support such activity” (Brown, 2009, p. 26).

This model is useful in considering the role of curriculum adaptation within a teachers’ repertoire of practices, however Brown (2009) admits that his conceptual framework does not include factors external to the teacher that likely influence how teachers use curriculum materials. This includes contextual factors such as the larger social and institutional setting, classroom culture and norms, the students themselves, teachers' professional identity, and professional norms. Stein, Remillard, and Smith (2007) assert that features of teachers, students, context, and curriculum all matter when understanding how teachers use curriculum. While these kinds of factors could be added to the DCE framework as arrows leading toward, and having influence over, the "Types of Use" bi-directional arrow at the center of the diagram, it is also possible to consider how the DCE framework, with its focus on teachers' cognitive resources and tool use, might be used in conjunction with an analysis guided by CHAT or social practice theory to understand the situated factors that influence a teacher's decision-making of one pathway or another as they use curriculum resources.

Framework #2: The Integrated Model of Professional Growth. Whereas Brown's (2009) model focuses on instructional outcomes, Clarke and Hollingsworth's (2002) conceptual framework provides a tool for understanding teachers' own professional learning and growth. Therefore, the Integrated Model of Professional Growth (IMPG) can be applied to teacher learning through co-design. At the heart of the IMPG is teacher change, which can be conceived of as growth or learning. The IMPG suggests that change, in our case, teacher professional learning, "occurs through the mediating processes of 'reflection' and 'enactment', in four distinct domains which encompass the teacher's world" (Clarke & Hollingsworth, 2002, p. 950). These four domains include: the personal domain, the external domain, the domain of practice, and salient outcomes. The model is useful whether teacher change is being considered through the lenses of cognitive, situative, or social practice perspectives (Clarke & Hollingsworth, 2002). Teacher learning as modeled by the IMPG occurs in a non-linear, interconnected way, with the potential for change—teacher learning—occurring in any of the domains. An important point is that processes of professional growth in the IMPG occur within the "enveloping change environment" and are impacted and influenced by the context's affordances and constraints (Clarke & Hollingsworth, 2002, p. 950), capturing dimensions that were missing from Brown's (2009) framework.

How does the IMPG work to model pathways of professional learning and growth? The IMPG can be used by researchers as an analytical, predictive, or interrogatory tool. For example, Voogt and her colleagues (2015) used the IMPG in their study of Teacher Design Teams in Ethiopia, Ghana, and Tanzania in order to understand teacher learning through collaborative curriculum design. In their study, teacher learning in the *personal domain* occurred through changes in teacher's beliefs, knowledge, skills, and classroom practice. In the *external domain*, teachers were introduced to new practices and strategies through their participation in the TDT, including technological pedagogical content knowledge (TPACK), design expertise, and instructional practices. Two *domains of practice* were identified within these design communities: teacher learning through co-design and teacher learning through curriculum enactment. In the *domain of consequence*, outcomes of the co-design initiative included changes in student interest, skills, and understanding of content. The unit of analysis for the IMPG framework is the multi-dimensional change environment. However in order to understand teacher learning within the context of design-RPPs, more granularity is needed to investigate the partnership and collaborative activities that occur within the external domain and the shifts to teachers' practice that occur within the domain of practice, and how those shifts are well supported or not by the members of the design team.

Framework #3: Integrated Descriptive Framework for Teacher Design Teams. Another framework that has been developed for understanding collaborative design is the Integrated Descriptive Framework for TDTs. Binkhorst, Handelzalts, Poortman, and van

Joolingen (2015) first developed a conceptual framework for understanding Teacher Design Teams (TDTs) based on theory, later refining it into a descriptive framework that integrated these theoretical insights with empirical data from an explanatory sequential mixed methods survey of 94 secondary teacher participants from fourteen university-led TDTs in the Netherlands. The Integrated Descriptive Framework includes input, process, and outcome factors. *Input factors* include teacher characteristics (e.g., teachers' motivation to participate, personal reform ambitions, design experience and teaching experience) and contextual characteristics (e.g., the school's reform ambitions, involvement of teachers in the reform, and conditions for supporting teachers). *Process factors* include team characteristics (e.g., team interaction, team coach, and goal alignment, activities within and outside of TDT meetings) and organizational characteristics (e.g., networked or school-based TDT, duration, location, composition of groups, time). *Outcome factors* include professional development (e.g., satisfaction, teacher learning, change in practice) and designed materials (e.g., perceived quality, actual use).

One contribution of this model is its focus on the role of a team coach, capturing the social (e.g., interactions in team) and relational (e.g., goal alignment) components of collaborative design work that was missing in the other frameworks. This model considers teachers' professional growth, learning, and change as an outcome of the collaborative work, but also includes the curriculum artifacts that were produced as a result of this work. However, student learning outcomes based on enactment of the designed materials is missing. Note that in this framework teacher learning is characterized as an outcome related to teachers' professional development. I would argue that teacher learning should also be explored as an input (i.e., teacher knowledge, beliefs, and professional identity) and a process factor (learning *in* practice), rather than solely as an outcome of the design work. It should also be noted that this framework was developed specifically to describe Teacher Design Teams. However, this framework could be helpful, in tandem with the other framework introduced previously, to predict, develop conjectures about, describe, analyze, and understand teachers' professional learning through participation in co-design in RPPs or other types of collaborative design communities.

Framework #4: Expansive learning in co-design. What learning occurs in the coordination of activity between the teacher and the external domain or the teacher and her domain of practice? How does a design team break trail as they create new forms of work activity while producing curriculum innovations? Engeström's (2001) concept of expansive learning, as influenced by activity systems theory, provides a conceptual model for thinking about why and how a design team engages in and learns through newly created forms of activity, in which learning is truly expansive. As Engeström (2001) describes it, expansive transformations occur as people engage in horizontal learning in the absence of a more competent mentor, in which new forms of activity are "literally learned as they are being created" (p. 13). Expansive learning happens through a cyclical process that includes: *questioning, analyzing, examining, implementing, reflecting,* and *consolidating* practice (Engeström, 2001).

Teacher learning through co-design activities may be considered as a form of expansive learning (Engeström, 2001). Voogt and her colleagues (2015) assert that the learning and change processes that occur during collaborative design are cyclical in nature, and that the design activities themselves are also cyclical. These researchers (Voogt et al., 2015) see parallels between co-design activities and Engeström's (2001) conceptual model of expansive learning in work groups, as they saw in their examination of three case studies of collaborative curriculum design. In expansive learning and in collaborative design, a work team is in the process of learning something that is unstable and unfolding, as the goal of the design work is to create an innovation is response to an opportunity of practice.

Each of the phases of co-design provide opportunities for expansive learning (Voogt et al., 2015). For example, during the initial phase of curriculum design that uses a design-based research approach, researchers and practitioners identify problems and opportunities of practice from prior research, literature, or student assessments (Gravemeijer & Cobb, 2013; Plomp, 2013); the expansive learning that may occur at this stage is the *questioning* of the existing practices. Engeström (2001) explains that a full cycle of expansive learning “may be understood as a collective journey through the zone of proximal development of the activity” (p. 137). When teachers, researchers, and disciplinary experts co-design and engage in reflective curricular discourse as part of their joint work, they operate within this zone of proximal development (van den Akker, 2013).

Four conceptual frameworks have been presented, each which can be applied to understand different areas of professional learning when teachers are engaged in collaborative design work. However, missing from the literature is a conceptual framework that adequately describes teacher learning within the specific structure of a design-RPP, such as: the types of expertise and shifts in practice that teachers develop through participation; the activity structures and practices that support teacher learning; the role of collaboration within the partnership; the influence of external and contextual factors; and the impacts of this teacher learning on their professional practice.

The Research Agenda: Teacher Learning through Co-design

There is much that the research community has yet to investigate regarding science teachers' learning, collaborative curriculum design, and participation in design-RPPs. With a focus on teacher learning, questions still remain, such as: How do science teachers learn curriculum design expertise within the community of a design-RPP and what practices and tools best support them in this process? What do teachers learn when they adapt, enact, and reflect on the redesign or refinement of curriculum materials within a design community? In what ways might teachers' practice change through participation in the reflective enactment and refinement phases of DBR? Does this form of collaboration impact teachers' beliefs and professional identities? Does this type of deep disciplinary engagement serve science teachers? How might the design team of a design-RPP function as a teachers' social network? What characteristics of design-RPPs support or constrain teachers' development of expertise and changes in practice? In particular, more research is needed to understand how co-design initiatives may support or constrain professional learning for early-career teachers.

Opportunities for Future Research

Learning scientists (e.g., Coburn & Penuel, 2016; O'Neill, 2016) have recently issued calls about the need for more research centered on the dynamics, successes, failures, and outcomes of the interconnecting activity systems that make up a RPP, as well as focusing on the collaborative practices and tools that arise through design work. Ethnographic research methods can be employed to develop design knowledge, including design principles, design narratives, and the description of design phenomena. Richly descriptive design narratives have the potential to share details about complex forms of cross-practice workplace learning and collaboration. It is also important to specifically focus our attention on design-RPPs within science education, to further develop our understanding of how and why science and engineering curricula should be developed within these kinds of collaborations, especially in the current push for reform-oriented curricula. There is also an opportunity for researchers to investigate how science teachers' participation in a design-RPP might serve as an alternative, practice-oriented approach to teacher professional development that is collaborative, social, sustained, and networked. We need to understand what forms of expertise teachers bring to co-design practices, what forms of expertise they develop through participation, and what shifts in classroom practice may occur. For example, researchers could focus on science teachers' development of various forms of expertise through co-design: such as expertise with core practices, disciplinary specific expertise such as phenomenon-driven science instruction or computational inquiry, curriculum design expertise, and repertoires of practice for collaboration. In particular, the literature is almost non-existent on exploring the affordances and challenges of involving early-career teachers in design-RPP initiatives. Partnership-based approaches to the collaborative design of K-12 science and engineering curriculum hold promise as fertile grounds for curricular innovations and professional learning, presenting many opportunities for future research.

References-Chapter 2

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Chapter 3: Role Fluidity Across (Im)permeable Boundaries of Partnership

A Case Study of a Boundary Spanner within a Research-Practice Partnership

Introduction

"I describe myself as like a liaison right now, between like you all and the school teachers that we work with. So I feel like I'm kind of like that person who makes sure the needs are being met on both ends."

~Ms. Cruz, Project Manager/Instructional Coach

Contemporary workplaces often require people from different work groups or institutions to come together to collaborate on shared projects. In these kinds of inter-institutional and cross-practice partnerships, the coordination of multiple perspectives and work practices is complex work that involves entering together into new, jointly-constructed social practices and encountering and navigating sociocultural differences (Akkerman & Bakker, 2011). Each person is situated within their own home institution or "institutional shelter" which itself is rooted in and influenced by social, cultural, historical, political, and economic dimensions (Sennet, 1999 as cited in Edwards, 2005; Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013). Each person on a collaborative team also comes to the project with their own professional identities, beliefs, norms, and areas of expertise.

As the partners engage in *joint work* (Penuel, et al., 2015; Penuel, Coburn, & Gallagher, 2013; Darling-Hammond & Richardson, 2009; Little, 1990), they may bump up against *boundaries*, which can be defined as "multiple cultural, professional, and organizational differences" (Penuel, et al., 2015, p. 188) between people or thought of as "sociocultural differences leading to discontinuity in action or interaction" (Akkerman & Bakker, 2011, p. 1). Boundaries are differences in perspectives or practices, for example, between and within organizations, work groups, professions, disciplines, or between research and practice (Akkerman & Bakker, 2011; Penuel et al., 2015). Boundaries may include differences in knowledge, norms, or power (Akkerman & Bakker, 2011). Boundaries can be physical (e.g., location, organization, work groups), social (e.g., divisions of labor, rules, social practices, social relations, membership categories), or mental (e.g., professional knowledge and expertise) (Hernes, 2003 as cited in Kerosuo, 2004). These boundaries, or sociocultural differences, can be viewed as a challenge to collaboration (Goodlad, 1988), or alternatively viewed as opportunities for expansive and generative professional learning (Akkerman & Bakker, 2011; Edwards, 2011; Penuel et al., 2015).

When sociocultural differences are viewed as boundaries and opportunities between territories, rather than obstacles, they are meant to be negotiated and crossed (Penuel et al., 2015). Joint work requires members of a design team or partnership to engage in *boundary crossing*, which can be characterized as "an individual's transitions and interactions across different sites of practice" (Akkerman & Bakker, 2011 as cited in Penuel et al., 2015). Boundary crossing may consist of identifying and recognizing boundaries and taking specific, intentional moves to find areas of common ground and pathways for joint work (Penuel et al., 2015). Over time, groups also coordinate their work by developing a repertoire of practices that is specific to the group and their shared purpose and which connects the members of the group (Wenger, 1998). Boundaries can be crossed by people (boundary spanners), objects (boundary objects), and through interactions, routines, and tools (boundary practices) (Akkerman & Bakker, 2011; Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013; Wenger, 1998).

Design-focused research-practice partnerships (design-RPPs; Coburn, Penuel, & Geil, 2013) that involve researchers and practitioners in collaborative design practices necessitate that partners redefine their roles and invent new work practices together (Coburn, Penuel, & Geil, 2013). Design-RPPs in particular are "often organized around specific boundary objects or boundary practices that enable collective change through the coordination of activity across the different tiers" of the organizations that make up the partnership (Penuel et al., 2016, p. 260). It is these objects, practices, moves, and interactions that a team develops and negotiates together that allows for boundary crossing to occur. In design-RPP communities, routines of collaborative design or co-design practices (Severance, Penuel, Sumner, & Leary, 2016) are often the main boundary practice with the designed educational innovations—curriculum materials or technologies—serving as the boundary objects. Individuals within a partnership may also play a boundary spanning role.

Gaps in the Literature

Researchers have focused on the challenges faced by the members of research-practice partnerships in education. Some of these common challenges include differing ideas about the focal problem, lacking a common language or work practice among participants, having to adapt to atypical norms of interaction and divisions of labor, developing trust in each other and the process, and holding different and at times conflicting expectations for the project (Coburn & Penuel, 2016; Penuel, Coburn, & Gallagher, 2013). Many of these challenges are salient to a discussion of boundaries and boundary crossing as part of highly collaborative work. Moreover, in hierarchically organized, multi-tiered RPPs in which both district and school leaders are engaged, challenges can arise from complex organizational structures, high turnover in staff, and the fact that these partnerships exist within a politicized environment consisting of multiple interest groups (Coburn & Penuel, 2016). University researchers may bump up against differences in how university, district, and school partners typically engage in their work. Issues of power, authority, and status can also introduce political and power-based boundaries to these partnerships, reinforcing the model of hierarchy that has plagued university-school partnerships (Carlone & Webb, 2006; Coburn & Penuel, 2016; Donovan, Snow, & Daro, 2013; Penuel, Coburn, & Gallagher, 2013; Penuel et al., 2016).

However, the literature base is thin on providing richly detailed accounts that center the role of boundary spanners within research-practice partnerships as they help to create shared boundary practices (for an example, see Penuel, Coburn, & Gallagher, 2013). How might these boundary spanners help the members of a partnership to articulate and intentionally develop boundary practices? Penuel and his colleagues (2015) noted that "although some boundary crossing is impromptu and occasioned by the need to make sense of emerging issues and concerns, it is possible to build in structures and routines that provide sustained opportunities for boundary crossing" (p. 192). As a team figures out how to collaborate and engage in joint work together, they will create new boundary practices while also making "explicit use of practices that are 'native' to each culture" (Penuel, Coburn, & Gallagher, 2013, p. 250). What role might a boundary spanner have in the development of new kinds of shared boundary practices? This research study fills a gap in the literature as it illuminates the sociocultural and institutional structures that support and constrain a boundary spanner's ability to cross boundaries to facilitate joint work.

Research Questions

This study examines the unfolding and shifting role of a boundary spanner within the Computational Science Project (CSP), a design-RPP. The CSP was a four year project that had the dual focus of engaging in collaborative curriculum design practices to produce computationally rich secondary science curricula and to study teacher, researcher, scientist, and student learning through an application of design-based research methodology. (See Chapter 1 for an in-depth description of the CSP, including its history, partner organizations, and approaches to collaborative curriculum design). In this chapter, I share a person-centered, micro-ethnographic case study of Ms. Cruz, a former science teacher within the CSP partnership who took on a boundary spanning role across the first three years of the project. Through a deep analysis of Ms. Cruz's experiences, I asked: *What roles did a person positioned as a boundary spanner take on in a design-based RPP, and who benefited from her participation? How did she cross the boundaries of the respective institutions in the partnership and in what ways was she constrained in this work?*

Framing Literature

The relational turn in cultural-historical activity theory (CHAT) and social practice theory provides two theoretical lenses for this study, centering on different units of analysis. The relational turn in CHAT focuses on understanding inter-professional and cross-practice collaborations at work (Edwards, 2005, 2011, 2012), providing a lens for focusing examinations on the relational aspects between the people engaged in work that takes place within the trading zones between the interconnected activity systems of a partnership. In this way, the unit of analysis is the coordination of work and boundary spanning that is accomplished between the interconnected activity systems. Social practice theory provides a compatible theoretical lens for understanding individuals' experiences as they engage in cross-practice design work within a design-RPP. Social practice theory questions how people learn and become who they are in different and fluid forms of social practice that unfold across both temporal and spatial dimensions (Dreier, 2016). This theoretical lens recognizes that social practices are not neutral or benign; they occur within institutional, cultural, and political-economic structures and struggles (Bell, Tzou, Bricker, & Baines, 2012; Dreier, 2016; Holland & Lave, 2009; Penuel, 2014). A social practice theory lens invites investigators to trace an individual's learning pathways through their different social worlds, with a focus on identifying contentious local practices and how they are situated in historically institutionalized struggles (Holland & Lave, 2009). A social practice lens can be useful for investigating a boundary spanner's professional learning trajectory, identity development, and change through her participation in the project, across roles and over time, as well as the roles made available to her through porous categories of work. In this way, the unit of analysis can focus on the boundary spanner as a person-in-practice (Dreier, 2016).

The conceptual framework for this study includes four concepts that are related to boundary processes in work teams. These concepts include the articulation process of projects, the components of relational collaboration, boundary crossing, and role-remediation. Each of these concepts will be described in the remainder of this section.

The Articulation Process of Projects

Based on his work in medical sociology, Strauss (1988) offers the *articulation process* as a theoretical framework for understanding the properties, processes (interactional and work), and tasks that constitute collaborative work projects. This articulation process can be defined as the organizational process that allows a project to be carried out, from the generation of the initial idea and alignment of vision through the achievement of results. It is "the overall process of putting *all* the work elements together *and* keeping them together" (Strauss, 1988, p. 164; emphasis from original). With this lens, there is an appreciation of the narrative histories and temporality of collaborative project work as it develops and changes over time (Strauss, 1988). For example, what may begin as a simple and routine project could evolve into something more complex due to unanticipated disruptions.

Articulation of project work is one aspect of the articulation process and is defined as "the specifics of putting together tasks, task sequences, task clusters—even aligning larger units such as lines of work and subprojects—in the service of workflow" (Strauss, 1988, p. 164). As an example, classroom data collection could be considered as a task cluster, as it includes the coordination and ordering of a variety of tasks among a team of researchers and a partner teacher, such as consenting research participants, purchasing batteries, prepping equipment, scheduling observations, setting up video cameras and microphones, taking field notes, and collecting classroom artifacts, all of which are articulated as part of the overall data collection plan for a study.

Particularly salient to this research study is Strauss' (1988) idea of interactional processes and work processes as part of the overall articulation process, and the idea that disruptions and unanticipated contingencies can affect these processes and trigger the need for explicit articulation of work processes in order to respond to the disruptions. *Interactional processes* are the relational work that occurs between people involved with the project and includes: persuading others, educating, negotiating exchanges, manipulating, and coercing. A subprocess is *interactional alignment*, or the way that workers coordinate and align their actions. *Work processes* include: "discovering and maintaining appropriate resources; devising and maintaining a division of labor; matching tasks and workers' motivations, [and] supervising delegated tasks" (Strauss, 1988, p. 175). A subprocess is the articulation of work for *subprojects*, including how they articulate with each other and how they articulate with the overarching project; this is accomplished through both interactional and work processes. Strauss (1988) notes that everyone across all levels of a project are involved in articulating the work, but that sometimes individuals are assigned to coordinate specific aspects of the work and are engaged in explicit articulating work. A boundary spanner may engage in explicit articulating work that focused on interactional alignment across physical, social, and mental boundaries.

Relational Approaches to Collaborative Work Projects

Interactional processes mediate work processes, with recognition that “work rests ultimately on interaction” (Hughes, 1971 as cited in Strauss, 1988, p. 167). As described in detail in Chapter Two, Edwards’ concept of relational agency, relational expertise, common knowledge are part of a relational turn in cultural-historical activity theory, in which the focus of analysis extends to the relationships and intersections of practices between individuals that make up a work group, in particular when collaboration occurs across the boundaries of professions, institutions, and practices.

Edwards’ (2012) three cultural-historical conceptual tools can be applied to understanding the boundary work that occurs in complex professional collaborations: relational expertise, relational agency, and common knowledge. First, *relational expertise* (Edwards, 2012) is an individual’s ability to identify, recognize, and engage with the expertise of other people in a collaboration, and integrate their own knowledge with the knowledge of others. Second, relational expertise is mediated by a development of *common knowledge*, the shared understandings or knowledge that is held in common among the members of a collaborative group (Edwards, 2012). Carlile (2004 as cited in Edwards, 2012) suggests that knowledge can be mobilized across practice boundaries through three processes: transfer, translation, and transformation. When a work group develops common knowledge, *transfer* of ideas can happen quickly and fluidly across practice boundaries, though sometimes some *translation* is required. Through inter-professional collaboration, knowledge can also be *transformed* when professionals think radically and creatively across the boundaries of practice (Edwards, 2012). In addition, a common language (also called a hybrid or pidgin language) may develop over time within a collaborative group, as a way that groups coordinate their work and signal an exchange (e.g., transfer or translation of terms and ideas) occurring within the trading zone of the partnership (Penuel, Coburn, & Gallagher, 2013). Importantly, Penuel, Coburn, and Gallagher (2013) assert that these kinds of hybrid languages that develop through partnership are indicators that a productive trading zone is forming in the boundary spaces. Third, *relational agency* is an individual's ability to relate to and work with others toward shared goals and involves process of relational engagement and responsive collaboration (Edwards, 2011).

Boundary Spanning

People can facilitate boundary crossing through their invention, negotiation, and use of boundary practices and boundary objects. However, an individual can also be the source of boundary crossing. The role of a *boundary spanner* is critical in many RPPs as it facilitates mutually beneficial interactions between the researchers and practitioners in the partnership (Penuel et al., 2016). A boundary spanner may belong to more than one sub-unit in an organization, thus spanning the boundaries between them. A boundary spanner may act as a conduit of information between their institution and a research-practice partnership, or may have one foot in the door of the institutions that make up the partnership. The boundary spanning role has been described in the literature on RPPs and teacher professional learning communities as a "go-between", "translator", "hub of communication", "buffer", "broker", and "boundary crosser" (e.g., Penuel, Coburn & Gallagher, 2013; Ford & Youngs, 2017; Russ, Sherin, & Sherin, 2016;

Wenger, 1998; Akkerman & Bakker, 2011). A boundary spanner may act to develop a common language among the members of the partnership. Edwards (2011) notes that individuals' professional multilingualism, or ability to speak the different languages of their home institution and partner institutions, may allow them to cross and negotiate practice boundaries. In addition, a boundary spanner may be involved in translating this specialized, hybrid language of the partnership to the broader community, which is especially important for implementation and dissemination of educational innovations.

As an example of boundary spanning within a design-RPP, Penuel, Coburn, and Gallagher (2013) described the trading zone in which researchers, district staff, and teachers collaborated on adaptations to a commercially-available science kit curriculum. The researchers observed a member of the partnership, who was initially employed as a district math coach, transition to becoming a learning sciences graduate student advised by one of the researchers in the partnership. In her new role as graduate student, she continued as a member of the partnership. This boundary spanner physically crossed over from one institution in the partnership to the other. She became able to span and leverage the perspectives, language, and professional practices of both a teacher and a learning sciences researcher. She also importantly became a "hub of communication" between the university and the district (Penuel, Coburn, & Gallagher, 2013). Based on this experience and those of others (e.g., Donovan, Snow, & Daro, 2013), Penuel, Coburn, and Gallagher (2013) suggested that boundary spanning positions could be intentionally created early in partnering processes.

As another example of boundary spanning that occurred outside of a RPP model, Engeström's (2008) ethnographic study of a school-based teacher design team used cultural-historical activity theory (CHAT) to examine the boundary crossing that occurred during five teachers' joint work. These elementary school teachers were motivated to collaboratively design and enact an integrated K-6 curriculum focused on global education. In this work, the teachers encountered, questioned, and crossed the "taken-for granted" mental boundaries of grade levels, classroom spaces, temporal units, and curricular subjects (Engeström, 2008, p. 88). The teachers also transformed social boundaries by redefining their norms around their roles, division of labor, discourse, and school rules (Engeström, 2008).

In some communities of practice, a person may play an important role in bridging the social worlds of a teacher's learning community with the administrative or organizational contexts in which it is situated. For example, in their study of professional learning during the implementation of a literacy program at an elementary school, Ford and Youngs (2017) identified that the program facilitators took on an additional role of fostering collegiality. As teacher-leaders, the program facilitators had one foot in the classroom and the other rested with the literacy organization and the school's administration. Due to the centrality that these facilitators developed within the social network of the school, they took on the role of a "buffer" between the teachers and administration, "mitigating the tensions and vulnerabilities among teachers and other school staff that invariably rise as colleagues begin to interact and work more collectively on challenging tasks" (Ford & Youngs, 2017, p. 10). This served both teachers and administrators, allowing teachers to "vent" without needing to go to the principal, and helping to "mend fences" for the principal (Ford & Youngs, 2017).

Role Re-mediation

As shown by studies of boundary spanning by Penuel, Coburn, and Gallager (2013), Engeström (2008), and Ford and Youngs (2017), people who act as boundary spanners may need to redefine, shift, and assume different roles within a partnership. In their exploration of partnering processes that purposefully seek to disrupt normative hierarchies and power inequities through a lens of participatory-design research (PDR), Bang and Voussghi (2016) introduced a salient concept that they call *role re-mediation*. This concept puts forth the idea that the individuals within a partnership can—if allowed—take on different roles if the categories of work (i.e., researcher, designer) are viewed as “porous” and “open to the questions, concerns, ways of knowing, and designing” that are already present in the community or that can be newly created through joint work (Band & Voussghi, 2016, p. 174). Role re-mediation can necessitate changes to or be the result of changes in the activity system of a partnership, in that it “involves a reorganization of the entire ecology for learning and ‘a shift in the way that mediating devices regulate coordination with the environment’” (Cole & Griffin, 1983, p. 70 as quoted in Bang & Voussghi, 2016, p. 174). These researchers push for an expansion of who gets to engage in design work and “who we define as designers, learners and theorists” through role re-mediation within PDR work (Bang & Voussghi, 2016, p. 181). By leveraging Edwards’ conceptual tools for understanding relational aspects of collaborative work, they also emphasize that PDR work should prioritize subject-subject relations that allow individuals’ roles to shift when categories of the work are defined so as to be open and porous. In order to engage in these types of role re-mediations or re-imaginings, it is important to understand how the relationships between people in a partnership develop, change, and are sustained.

These four concepts—articulation of work projects, relational approaches to collaborative work, boundary spanning, and role re-mediation—provide a coherent conceptual framework to analyze Ms. Cruz’s case. This conceptual framework directs attention toward how a relational approach and an ability to articulate the work processes of different teams in the partnership may have helped Ms. Cruz span boundaries. It focuses on the role categories that were porous and available to her, and the ways in which Ms. Cruz moved fluidly through these roles in response to emergent needs within the project. This framework also provides a lens for analyzing the challenges that she faced in navigating and crossing boundaries.

Overview of the Case Study

This case study is situated within the larger work of the Computational Science Project (CSP), a design-RPP funded by a grant by the National Science Foundation. The CSP was funded to employ collaborative design practices to develop, enact, and study computationally-rich curriculum for use in secondary science classrooms. The CSP was co-managed by principal investigators (PIs) from two key partners, the university and STEM Foundation, a non-profit STEM-focused educational organization. The other two CSP partner institutions were the school district and STEM Academy, a public school located in a suburban neighborhood that served students from culturally, linguistically, and financially diverse families. STEM Academy was known for its use of project-based learning (PBL) pedagogies (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2005), which includes engaging students in extended, interdisciplinary projects. STEM Academy operated under a unique arrangement in which it was co-managed by the school district and Tech Foundation. (See Chapter One for additional details about the CSP and its partner institutions.) This chapter presents a case study that extended through the first three years of the CSP partnership. During that time, the district asked Tech Foundation to lead the merger of STEM Academy with Cascade School, an under-performing public middle school. In Year Three of the CSP, these schools merged to form Cascade STEM School, a public neighborhood school serving students in grades six through twelve. As part of the merger, STEM Academy students and teachers moved to the former Cascade School site, undergoing a major transition in the number of students and teachers and encountering sociocultural and professional differences between the communities of teachers and students from the two original schools. This complicated, shifting landscape forms the backdrop for this case study.

Throughout the CSP, individuals from different role categories engaged in boundary spanning work, developing practices for joint work across the institutional, sociocultural, and professional boundaries. Researchers at the university served as the persistent and reliable partner (Donovan, Wigdor & Snow, 2003) in the CSP partnership, as the partner school, foundation, and district all went through significant changes, including turnover in personnel. The university researchers led partnering processes, project management, grant administration, curriculum design, and research activities, work that unfolded across the contexts of the partner institutions. Foundation staff served as a co-PI for the CSP project, and supported grant administration and project management activities. Science teachers at STEM Academy and Cascade STEM School engaged in collaborative curriculum design activities, enacted the designed curriculum in their classrooms, and served as research partners throughout the CSP.

This case study focuses on Ms. Cruz, who had worked as a public school science teacher for a total of five years, with additional experience as a student teacher. At the beginning of the CSP, Ms. Cruz was in her early-thirties and unmarried. She described herself as Mexican American and had grown up in a rural community in the Pacific Northwest. Ms. Cruz's mother worked at a preschool, providing her with many opportunities to volunteer with young children. Ms. Cruz moved across the state to attend college at a large, urban public research university where she received a bachelor's degree in chemistry. Rather than engaging in lab research as an undergraduate to prepare for a career as a chemist, she worked on an educational outreach program in a chemistry research lab. Ms. Cruz later returned to the same university for her master's degree in teaching. Her first two years of teaching experience included teaching at a public urban middle school and a public suburban high school. For her third year of teaching, she accepted a positon as a science teacher at STEM Academy, located in a suburban area. At the time, the school was reported to be in the most diverse school district in the state based on ethnic/racial student demographics. In her three years as a teacher at the school, she taught eight grade science and high school physics for one year, chemistry her second year, and physics her third year.

During the three years of this case study, Ms. Cruz became married, welcomed her first child, and dealt with her mother's serious illness. During her tenure with the CSP, Ms. Cruz moved through two jobs at two of the CSP partner institutions and was specifically assigned within the CSP in a boundary spanning role. Ms. Cruz held different roles with the CSP partner institutions: a science teacher at STEM Academy; an instructional coach at STEM Academy and later at Cascade STEM School; a member of two school District committees; a CSP project manager for Tech Foundation; and a planning partner and research collaborator with the university. In this way, she took on a boundary spanning role in the CSP partnership across institutions, settings, practices, and time. Throughout these experiences, Ms. Cruz fluidly moved through different roles in order to conduct her work but struggled to balance them. After returning from maternity leave, Ms. Cruz resigned from her position at Tech Foundation toward the end of Year Three of the CSP. She later transitioned to a position as a science curriculum designer at a non-profit education organization. Despite all of these changes and demands on her time, Ms. Cruz presented herself with a professional and calm demeanor. She was warm, friendly, and quick to laugh. She was clearly busy, and oftentimes scrambling to meet the demands of her position and multiple roles. However, Ms. Cruz seemed unflappable, collaborative, and open to others' ideas.

Ms. Cruz's professional trajectory during her tenue with the CSP is outlined below, with additional details shared in the Findings section of this chapter:

- Year 1: Science Teacher at STEM Academy (resigned)
- Year 2: Project Manager/Instructional Coach at Tech Foundation and STEM Academy
- Year 3: Project Manager/Instructional Coach at Tech Foundation and Cascade STEM School (resigned)

Methods

Study Design

This design-based research (Bell, 2004; The Design-Based Research Collective, 2003) study examined a particular thread of research as part of the larger research endeavor of the CSP, and therefore focused on a sub-set data from the available data corpus. Analysis of this data led to the development of a qualitative, micro-ethnographic case study of Ms. Cruz with a particular focus on her positioning and practice as a boundary spanner within the CSP. This section describes the methodologies I employed and shares a summary of the data collection and analysis processes.

Design-based research (DBR) is a meta-methodology commonly used for studying partnering processes, collaboration, learning, and design within RPPs (The Design-Based Research Collective, 2003). In DBR, researchers and practitioners partner to collaboratively design, enact, and redesign educational interventions (i.e., curriculum unit, educational software) in iterative cycles that take place in authentic and naturalistic settings. In addition to this design focus, DBR has the dual goal of integrating empirical research of the design and enactment processes. DBR can be employed to generate design knowledge (through design narratives, design patterns, and design principles) and theories of learning, to design educational interventions (design artifacts), and to broadly diffuse these interventions by bringing them to scale (Bell, 2004; Bell, Hoadley, & Linn, 2004; The Design-Based Research Collective, 2003).

During the design of this dissertation study, I engaged in conjecture mapping (Sandoval, 2014), a technique created specifically for educational design research as a means for identifying high-level conjectures about how to design for learning in a specific context and for predicting how they will function (through embodiment and mediating processes) to produce the desired outcomes in a way that can then be empirically tested. When planning the design of this particular study, I developed a conjecture chain for this chapter—a detailed tracing of one thread through the broader conjecture map (P. Bell, personal communication, 2015). This conjecture chain is centered on the role of Ms. Cruz as a boundary spanner and her observable interactions that served as mediating processes, notably instances of boundary crossing between institutions and practices of the partnership and the development of a coaching relationship between the science teacher Ms. Ly and Ms. Cruz. It was my conjecture that activity structures, routines, tools, and materials functioned as boundary practices and objects that facilitated Ms. Cruz's ability to act as a boundary spanner. This study was designed to interrogate that conjecture.

Methodology

The methodologies of ethnography and case study guided this research study. Design narratives, a type of case study, are rich descriptions of the context, tools, activities, practices, assessments, and outcomes of DBR studies (Bell, Hoadley, & Linn, 2004). These narratives capture the stories of a design team and the evolution of designed products. With this study, I employ single case study methodology (Stake, 2005; Yin, 2014) as a way to examine the boundary spanning experiences of a single individual within the bounded activity system of the CSP partnership. Through the use of ethnographic field methods, including the use of ethnographic observations, field noting, and interviews, and through participation in the events and communities of interest (Blomberg, Giacomi, Mosher, & Swenton-Wall, 1993), data helped me to build a "thick description" (Geertz, 1973; Merriam & Tisdell, 2016; Stake, 2005) of the case so that readers can vicariously experience it, drawing their own conclusions and comparisons. In particular, ethnographic field notes in coordination with video and audio recordings allowed me to compare, supplement, corroborate, or correct my field notes with the recordings. I recognize, though, that both the observer and the camera lens and microphone placement can be biased in what they record (Blomberg et al., 1993; Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016). With case study methodology, important case data may include: a) the case, its activity, and its functioning; b) the case's historical, physical, cultural, economic, political, legal, and aesthetic dimensions and contexts; c) other cases through which it can be recognized and understood; and d) informants who have perspectives that can help illuminate the case (Stake, 2005). It is important to note that the case study of Ms. Cruz presented in this chapter should be considered as an embedded case (Stake, 2005) as it is a case study within the larger case of a design-RPP focused on the co-design of reform-oriented science curriculum materials.

Data Collection

Data collection within the partnership occurred throughout all three years of the CSP and included interviews, observations, and artifacts. I was involved in these data collection activities in collaboration with other members of the research team. These data collection activities are described below.

Interviews. I conducted five semi-structured interviews with Ms. Cruz at the following times: after the chemistry unit enactment at STEM School in Year 2, when Ms. Cruz recently transitioned from a teacher at STEM Academy to the project manager/instructional coach at Tech Foundation; at the beginning of the Year 3 school year with the Cascade STEM School merger underway; before and after the biology evolution unit enactment at Cascade STEM School in the beginning of Year 3; and at the end of the summer in Year 3 just before Ms. Cruz left her position at Tech Foundation to transition to a new job. Interviews were conducted in person or virtually through videoconferencing. The protocols developed for each interview included constructs that were inspired by framing literature and from ongoing data analysis. These constructs are shown in *Table 3*. Ethnographic field notes, video/audio recordings, transcripts, and analytical memos were produced for each interview.

Table 3. Constructs Across Ms. Cruz's Five Semi-Structured Interviews

Construct	Interview Number
Her Background, Professional Identity, and Pathway	1, 5
Articulation of Job Responsibilities and Roles	2, 3
Expertise and Professional Learning	5
Teacher Coaching and Support	2, 3, 4
Definition of Collaboration	1, 3, 4, 5
Reflection on Curriculum Design	3, 4
Reflection on Unit Enactment	1, 4, 5
Reflection on School Merger	4
Identifying Boundaries	4, 5
General Reflections	1

Observations. The data corpus included ethnographic field notes, collaborative analytical memos, and video/audio recordings. These were produced by the research team during six observations of a biology class in which Ms. Cruz co-taught with Ms. Ly, the biology teacher. Recordings, field notes, and artifacts were also collected during fifteen post-instruction debrief sessions with Ms. Ly, Ms. Cruz, and myself following their co-teaching experiences.

Artifacts. A debrief spreadsheet that contained 31 entries was used to capture data from Ms. Ly and Ms. Cruz's almost-daily post-instruction reflections during enactment of the biology evolution unit. Critical email correspondences between Ms. Cruz and researchers prior to and during unit enactments were also captured.

Field notes. Collaborative notes of weekly partnership planning meetings, which Ms. Cruz attended as project manager, were kept by the research team and Ms. Cruz during all three years of the project.

Data Analysis

The data plan in *Appendix C* details the alignment between my analytical questions, data sources and types, and methods of analysis. The key data source for this chapter is Ms. Cruz's interviews. Therefore, discourse analysis with a focus on Ms. Cruz's boundary discourse became the primary analysis method, as described in detail below. Open coding as guided by the tenants of grounded theory (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016) was employed to analyze field notes, interviews, artifacts, and analytical memos (Strauss & Corbin, 2008). Analysis of Ms. Cruz's interviews led to the identification of key excerpts across other data sources, which were also analyzed through coding. The four phases of data analysis are described in detail below: ongoing, retrospective, thematic, and comparison.

Phase One: Ongoing analysis. Data analysis began during data collection and continued throughout all three years of the CSP through the drafting of researchers' in-process analytical memos (Emerson, Fretz, & Shaw, 2011; Strauss & Corbin, 2008) after the occurrence of each data collection activity. These memos were then leveraged by the research team as we engaged in theoretical sampling (Charmaz, 2001; Corbin & Strauss, 2008) to identify additional data to collect throughout the lifespan of the CSP.

Phase Two: Retrospective analysis. Ms. Cruz's interviews were identified as the key data source for this study. I engaged in retrospective open coding (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016) through the use of content analysis (Merriam & Tisdell, 2016) and discourse analysis of her interview transcripts, after checking them for accuracy against the video files. Content analysis involves a process of developing codes and categories from "relatively unstructured data in view of the meanings, symbolic qualities, and expressive contents they have, and of the communicative roles they play in the lives of the data's sources" (Merriam & Tisdell, 2016, p.179). *In vivo* codes emerged from the data through the use of an inductive, line-by-line open coding of Ms. Cruz's interview transcripts using grounded analysis (Charmaz, 2001; Strauss & Corbin, 2008). I also engaged in deductively coding of transcripts for salient *a priori* concepts from the study's conceptual framework (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016).

Phase Three: Thematic analysis. Next, I engaged in a process of thematic analysis in which codes that were relevant to the research questions were organized into categories through a process of *axial coding* (Merriam & Tisdell, 2016; Strauss & Corbin, 2008). At times, I returned to the interview transcripts to probe the data, looking for additional examples of codes and categories. I drafted an analytical memo for each of these thematic categories that pulled together excerpts from across the five interviews (Emerson, Fretz, & Shaw, 2011; Strauss & Corbin, 2008). *Table 4* provides the major categories and codes from the code book, but does not report the many sub-codes that made up each code.

At this phase of analysis, I turned my attention to Ms. Cruz's boundary discourse, or how she expressed and talked about boundaries (institutional, sociocultural, or professional), her instances or attempts of boundary crossings, and the effects of these boundaries on her work. Like Kerosuo (2004), I focused on the partnership interactions that involved "the questioning and negotiation of the boundaries embedded in the structures, values, relations, and practices of interorganizational interactions" (p. 56). A cultural-historical activity theory (CHAT) lens paired with activity systems analysis allows for the analysis of discursive actions from transcripts that surfaced tensions, challenges, and disruptions as the drivers of development and change within the activity system (Engeström, 2008). I also identified tools for collaboration and social practices that emerged to "promote learning and transfer across boundaries" (Kerosuo, 2004, p. 39). Discourse analysis also was a tool for examining how Ms. Cruz articulated interactional processes, providing insights into her own relational agency and expertise (Edwards, 2005, 2011, 2012), the development of common knowledge among CSP members (Edwards, 2011), and the evolution of a common or hybrid language (Penuel, Coburn, & Gallagher, 2013) between Ms. Cruz and the researchers in the CSP partnership. Discourse analysis of Ms. Cruz's interviews also guided my examination of how issues of power relations and hierarchy structures played out through language and social practices in the partnership (e.g., Kerosuo, 2004).

Table 4. Code Categories and Major Codes Identified from Analysis of Interview Transcripts

Code Categories	Major Codes
Professional Trajectory and Identity	Ms. Cruz's Background
	Ms. Cruz's Professional Identity
	Ms. Cruz's Professional Pathway
	Shifting Jobs, Roles, and Nature of Involvement in the CSP
Collaboration and Professional Learning through Partnership	Ms. Cruz's Professional Learning through the CSP Partnership
	Ms. Cruz's Definitions of Collaboration within the CSP
Boundary Discourse	Identification of Boundaries
	Boundary Work, Ways She Attempted to Span Boundaries
Articulation of Challenges to the Work	Structural Challenges, in general
	Structural Challenges, specific to school merger
	Tools and Practices to Navigate Structural Challenges

Expertise and Boundary Spanning Role	Importance of a Boundary Spanning Role for a RPP
	Areas of Expertise Ms. Cruz Brought to the Partnership
	Areas of Expertise Represented by Others in the Partnership
	Areas of Expertise Needed for Someone in a Boundary Spanning Role

Phase Four: Comparison across data sources and types. The coding of Ms. Cruz's interviews in phases two and three surfaced themes and pointed me toward particular moments that I tracked back to other data types or data sources. I offer some of these vignettes in this chapter to help illustrate important findings. In addition, at this phase data sources were again consulted in order to develop the *thick description* for Ms. Cruz's case study (Geertz, 1973; Merriam & Tisdell, 2016; Stake, 2005).

Researcher positionality. Ms. Cruz was one member of the CSP's planning team, which also included five learning sciences researchers: a professor of learning sciences who directed the project as the Principal Investigator; a post-doctoral researcher with a background as a science teacher and ecologist; a graduate researcher who was formerly an evolutionary biologist; a graduate researcher with a background as a science teacher and a marine biologist; and myself, a graduate researcher with expertise in curriculum design and science education program management. At times, we also partnered with key teacher-designers from STEM Academy/Cascade STEM School. Data collection activities were coordinated through collaboration between myself and two other graduate researchers; however, I conducted all five of Ms. Cruz's interviews affording us approximately five and a half hours of in-depth conversations together.

Before either Ms. Cruz or I became involved in the CSP, we knew each other from a different context. As a novice teacher, Ms. Cruz had participated in a summer research experience at an engineering research center at the University. I was the manager of that program at the time, and over a seven-week period, met with Ms. Cruz and other participating teachers to provide coaching in the design of engineering education curriculum materials. I had also made a visit to Ms. Cruz's classroom at STEM Academy as part of that program to observe her enacting lesson materials she had co-authored.

Findings & Discussion

Ms. Cruz was specifically positioned in a boundary spanning role within the CSP partnership across the interconnected activity systems of the school, district, foundation, and university. Her job at Tech Foundation positioned her as a boundary spanner between the foundation and school. In that role, she articulated work processes among the science and math teachers and helped to implement Tech Foundation's vision of STEM education through PBL. Ms. Cruz crossed institutional boundaries as she physically carried out her work at the foundation's offices, the school buildings, and the university campus. She crossed sociocultural boundaries as she became involved in developing new ways of working together through the CSP's cross-practice and inter-institutional partnership. Ms. Cruz transitioned through multiple roles that were available to her in order to carry out this complex work. She also encountered professional differences of knowledge, expertise, tools, and resources, engaging in professional learning throughout her three years with the project.

In this section, I share a case study of Ms. Cruz as a boundary spanner in the CSP partnership. I organize findings into five sections, each which focus on a particular lens and unit of analysis. I begin by describing how Ms. Cruz's role shifted over the three years she was involved in the CSP as a way to share examples of how Ms. Cruz helped to articulate work processes between the interconnected activity systems that made up the CSP partnership.

Second, I highlight how Ms. Cruz leveraged relational collaborations within the partnership to span boundaries. Third, I focus on Ms. Cruz as a person-in-practice, and how her experiences within the CSP partnership impacted her professional learning trajectory. As part of this, I describe a critical incident that caused researchers to realize they had made assumptions about how Ms. Cruz's vision and approach to the work aligned with their own. I then describe how Ms. Cruz leveraged different types of expertise to help CSP partnership work carry forward in the midst of a major disruption—the school merger that introduced new boundaries and amplified existing ones. I conclude by presenting an example of a role category that was not as available to Ms. Cruz and sharing her thoughts on how the boundary between herself and the researchers felt at times to be impermeable. *Appendix D* provides a summary of the Ms. Cruz's shifting roles, the boundaries she encountered, and the practices and tools she employed to engage in boundary spanning activities.

Spanning Boundaries between the Interconnected Activity Systems of the CSP

I begin by describing Ms. Cruz's professional trajectory through her participation in the CSP, with a lens focused on how Ms. Cruz articulated work to span boundaries between the interconnected activity systems of the partnership. Ms. Cruz was involved in the CSP partnership for three years. She began as a science teacher at STEM Academy. She then transitioned to the role of project manager/instructional coach employed by Tech Foundation in which she became an integral member of the CSP core team. In that job, she was expected to engage in work tasks that spanned the institutional boundaries of all four partners that made up the CSP partnership: School, District, Foundation, and University. In that role, she first worked with teachers at STEM Academy, and then continued with that work at the newly merged Cascade STEM School. In just three years, Ms. Cruz moved through two professional positions and across two school settings and the CSP partnership. Different categories of roles were porous and available to her, such as teacher, instructional coach, project manager, curriculum designer, event coordinator, committee member, and learner. Her trajectory through these roles is summarized in *Figure 5* and described below. Two important moments are highlighted on the figure which are further described in this Findings section.

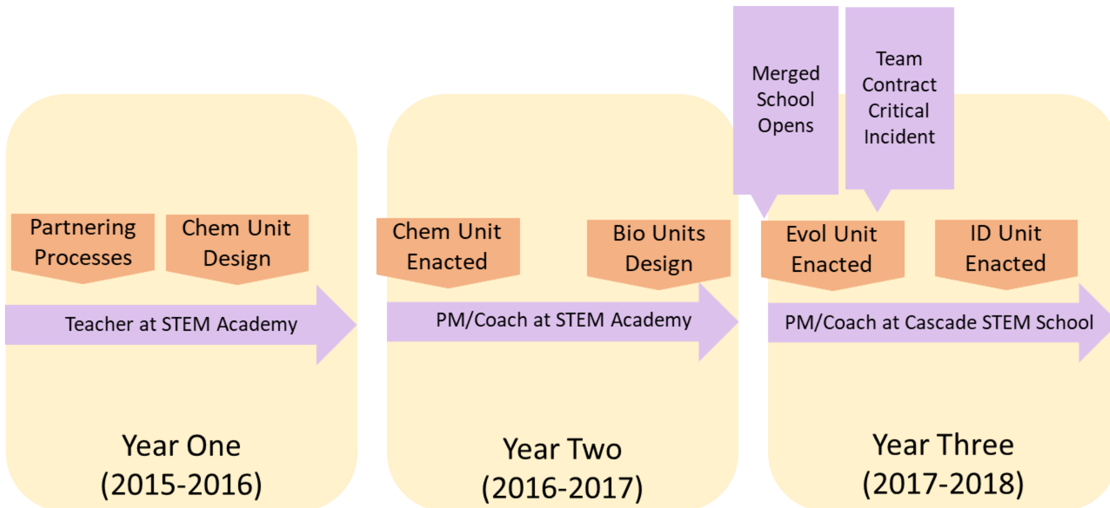

Figure 5. Ms. Cruz's trajectory through her participation in the CSP included positions as a teacher and project manager/instructional coach (PM/Coach). Major design activities included the design and enactment of a chemistry (Chem) unit, a biology evolution (Evol) unit, and a biology infectious diseases (ID) unit.

Science teacher at STEM Academy: Year One of the CSP (academic year 2015-2016). During Year One, Ms. Cruz was a science teacher at STEM Academy where she had taught middle school science and high school physics and chemistry courses. She also participated in a district science leadership committee in which teachers provided recommendations on the district's rollout of the NGSS standards. In the early days of the partnership, during her third year as a science teacher at STEM Academy, Ms. Cruz joined the CSP as a teacher-designer. She joined other STEM Academy middle and high school science teachers to in co-design meetings focused on the design of a CSP chemistry unit. Ms. Cruz and two other high school teachers, Ms. Eider and Mr. Sherman, were positioned by their principal to be the key teacher-designers in this effort, with the other teachers playing a supporting role. Ms. Eider and Mr. Sherman were both early-career science teachers, in their second and first years, respectively. Ms. Cruz was able to participate in six of the thirteen design sessions. These sessions were an important part of the CSP's partnering process in which the project's shared vision, curriculum design approach, research agenda, and collaborative practices began to develop.

When reflecting back on these early experiences, Ms. Cruz noted that not being able to participate in all of the early partnership forming meetings and co-design sessions for the chemistry unit impacted her early feelings about her role in the project. She felt distant to the work, recalling,

> I wasn't at all the meetings when we first started fleshing out the partnership. I think I was only at a couple. And so I felt somewhat disconnected from that and then during the chemistry unit, I came in after you guys had already decided what, you know, what the end product would be. And so just trying to help fill in gaps. Which was a little bit more challenging than what I'm used to doing.

Ms. Cruz encountered many structural challenges as a teacher at STEM Academy, and though she was excited about the CSP, it represented one more ask of her time. During her interviews, Ms. Cruz revealed some of these structural issues at STEM Academy, including the burden placed on teachers who were assigned to teach a different subject each year, who were assigned to teach courses outside of their certification, and the general lack of a provided or common curriculum. In her opinion, these structural issues at the school resulted in teachers never being able to get their feet under them. In five years of teaching at STEM Academy and two previous schools, Ms. Cruz never taught the same course two years in a row and was never provided with a curriculum. Ms. Cruz was inventing her course curriculum every year for five years running.

Ms. Cruz was hired by STEM Academy as a chemistry teacher, which was her area of expertise. She was then told by the principal that she would actually teach physics instead, only to be told later that she would also be teaching an algebra class. Ms. Cruz refused, unwilling to teach math outside of her certification. She told the principal she would take another job, he acquiesced, and the math class was removed from her teaching load.

> During my hiring he told me I was gonna teach chem. Then he called me and said, "No, actually we need a physics teacher." And I said ... So I had to really think about that. Is that what I want to do? And finally I agreed. Then he called me back and said, "Actually, we need you to teach physics and algebra." I said, "Nope, I draw the line at that, I'm not doing it, I'm taking the other job." And he said, "Okay, okay, okay, okay, you can just teach physics."

This was a common practice at STEM Academy, with the science teachers at the school routinely assigned to teach math classes outside of their certification and in addition to their science course load. The other teachers featured in Chapter Four were required to teach math in addition to their science courses. A structural issue that threaded across Ms. Cruz’s interviews was that she and the other science teachers at STEM Academy seemed overwhelmed and overworked. In one of her last interviews, she rationalized this as being part of working at a small school. She elaborated, “I started to realize quickly that working at a small school you take on a lot more responsibility because there's so many, there's so many jobs that need to be filled but not very many people to fill them.”

At the end of that school year, Ms. Cruz resigned from her teaching position at STEM Academy. In an interview, she described her reasons for leaving her position, stating that, “I left because I was overwhelmed”, that it was “stressful”, and that “it was a collection of things”. Therefore, Ms. Cruz was not involved in the intensive CSP co-design sessions that occurred over the following summer focused on the development of a chemistry curriculum unit. Ms. Eider became the lead teacher-designer in this work, with support from Mr. Sherman. At the time she resigned, Ms. Cruz planned to look for teaching positions at other schools.

While Ms. Cruz did end up leaving the teaching profession, she soon returned to the CSP in a new role. After she resigned, Tech Foundation let her know that the position of STEM project manager/instructional coach had become available. The person who had held the position before had resigned for health reasons. Ms. Cruz reflected, “it looked like a great opportunity. It looked like an area for me to grow in”. In particular, Ms. Cruz was interested in “the fact that I got to do a lot of that leadership work without the teaching piece, without grading and everything else that comes along with teaching. So I thought it was a good way to grow professionally”. Ms. Cruz noted, “but I love [Tech Foundation], I love the mission, I agree with it, I’m on board” and so she was open to any future opportunities with the foundation. Tech Foundation offered Ms. Cruz the position of project manager/instructional coach at the end of July. She hoped that this new position would allow her to continue to carry out the mission of the school and foundation in a role that would relieve her from the overwhelming stress she had encountered as a teacher at the school.

Project manager/instructional coach at STEM Academy: Year Two of the CSP (academic year 2016-2017). During Year Two, Ms. Cruz was just beginning her new job as project manager/instructional coach as the academic year began. Her new position included the dual role of managing CSP project tasks for the Tech Foundation, engaging in curriculum design sessions, providing instructional coaching to science and math teachers at STEM Academy, and coordinating career-connected STEM experiences for students at the school.

CSP partnership activities. Ms. Cruz’s role in supporting the CSP partnership activities included attending weekly project planning meetings with the research team, which were held at the university campus. Within the CSP, Ms. Cruz delineated her role as a liaison and communication conduit between Tech Foundation and the university researchers. She explained, “I’m communicating like [Tech Foundation’s] meetings and just their viewpoint, 'cause I'm ... and then the [University] side, so I feel like I'm kind of in between sometimes. I'm helping to keep the communication lines open and flowing.” Beyond that communication role, Ms. Cruz felt that her role was “filling in where I can,” such as with the curriculum work, she “tried to figure out where could my skills be utilized, and I kind of just put myself in there.”

CSP curriculum enactment. That fall, three teachers—Ms. Eider, Mr. Sherman, and Ms. Ly—enacted the newly designed CSP chemistry unit. Ms. Cruz had been involved in some of the co-design sessions and lent both her science teaching knowledge and her chemistry disciplinary knowledge to the curriculum writing process. However, she did not have a specific classroom role during the enactment of the unit, noting “everything was more of a hands-off approach where I wasn't connected as much to the teaching portion.” During the unit enactment, Ms. Cruz dropped by the teachers’ classrooms at times to observe or assist with a specific activity and engaged the teachers in occasional debriefs. She also reported back on the progress of the unit during weekly CSP planning meetings. Researchers were also in the classroom during the enactment for data collection purposes.

STEM Academy responsibilities. Outside of her CSP work, Ms. Cruz was also responsible for providing instructional coaching to five science teachers and two math teachers at STEM Academy. As part of her coaching role, Ms. Cruz saw it as her duty to advocate for the teachers, build relationships with them, and in the case of Ms. Eider, an early-career teacher who was struggling with health issues, it was her responsibility to check in with this vulnerable teacher and encourage her own self-care.

As part of her new job, Ms. Cruz's role at the school was also to coordinate special STEM educational opportunities for students—especially competitions and partnerships with external organizations. The school was known for these STEM connections and learning opportunities, however Ms. Cruz noted that many of the partnerships were temporary in nature, taking an investment of time and resources to develop and generate buy-in, but not being sustained long term. Later, Ms. Cruz also became responsible for organizing the school-wide STEM Symposium in which students investigated interest-driven, extended STEM projects and then presented them at a culminating symposium. Ms. Cruz admitted that the enormity of the task at times interfered with her ability to keep up with her CSP partnership and teacher coaching responsibilities. Consequentially, she felt unsure of her role within the partnership and her ability to meet expectations.

When asked during her first interview to consider her role within CSP, Ms. Cruz responded by questioning her role and her confidence in her ability to balance all of its components and achieve expectations:

> Ms. Cruz: Right now, I'm ... I don't know for our next unit what my role's gonna be. I'm a little unclear on that, and so I guess I was gonna ask you at some point like ... I don't know, I don't know if we really talked too much about my role other than I kind of grasp [inaudible], I don't know. I'm a little confused about my role, to be honest.
>
> Kristen: Really? And from our project side?
>
> Ms. Cruz: Well, I wonder if I'm doing enough. That's what I've wondering, if I'm doing enough, yeah.

This conversation continued as Ms. Cruz and I discussed her role and I emphasized the valuable contributions she was making to the project. She responded, "Oh really? I was looking at you to say, 'Yeah, yeah, you're doing the right thing.' Yeah my role just I feel like I'm ... my job serves like a dual purpose. Like me supporting the teachers also, I feel like, helps the [CSP] stuff." Ms.

Cruz was looking for confirmation that she was fulfilling expectations with the CSP research team, while at the same time expressing her difficulties in balancing two competing roles: CSP collaborator and instructional coach. Ms. Cruz continued, sharing her worries that she was not supporting the teachers well, although she was trying to meet with them each once a week. Ms. Cruz noted however that she had not been meeting regularly with Mr. Sherman. In her think-aloud, Ms. Cruz shared, “So I need to work him back into my system. I'm trying to figure out a balance, like how can I best help our teachers? And so that I think will help my [CSP] work, I think. I think maybe if I just focus more so on like [STEM Academy teachers], that might benefit us all.” Here, Ms. Cruz captured the complexity of her multiple roles across the partnership, the school, and the foundation and her commitments to researchers and teachers. She identified the demands on her time and improvised a strategy for better supporting all of the science teachers.

Project manager/instructional coach at Cascade STEM School: Year Three of the CSP (academic year 2017-2018). During Year Three, Ms. Cruz’s role and job tasks shifted again in preparation for and response to the merger of STEM Academy with Cascade School (see Chapter 1 for additional details on the school merger) and for the enactment of the biology unit in Ms. Ly’s classroom. This merger resulted in the creation of the new Cascade STEM School, which opened in the fall and represented a major disruption to the interconnected activity systems of the CSP. At the same time, Ms. Cruz’s responsibilities to the CSP project increased as she became involved in providing feedback during the design of two biology units in which Ms. Ly became the key partner-teacher. Ms. Cruz also became heavily involved in supporting the enactment of one of these biology units in the fall, which included developing new co-planning, co-teaching, and debriefing practices with Ms. Ly, who was a second-year teacher encountering a biology course for her first time. Ms. Cruz later reflected on the impact of being a part of multiple components of the CSP project in Year Three and spanning multiple boundaries. She commented:

> This past year was my first year that I was a part of the whole --- and that was definitely more helpful. I felt more present, I felt like I was, even though there were a lot of requirements on the [Foundation] side, I still felt like I was a part of this process more so than I was the last two years.

Ms. Cruz's role in co-teaching during the curriculum enactment, while demanding of her time, helped her to feel more connected to the project as a whole than she had in the past.

During the first year of the project, it was noted that STEM Academy had a large number of early-career teachers, which included student-teachers, first or second year teachers, and Teach for America (TfA) corps members. This may have been by design, as the principal at the time had sought out teachers who were open to Tech Foundation's transformational vision. Now with the launch of the merged Cascade STEM Academy and the dramatic growth of the student and staff population, the faculty now included a blend of these young novice teachers with teachers from Cascade School and new hires. Alicia noted that many of the Cascade teachers who stayed on during the merger were second career teachers, teachers who were new to the district, and many who were brand new to project-based learning. While it was Ms. Cruz's job to support all of the science and math teachers at Cascade STEM School, like she had at STEM Academy, she had no specific role to provide special support to the early-career teachers. She stated, "I make it my personal duty" to support and advocate for these young teachers. However, this was just one more duty she took on in a job that was already difficult for her to balance.

At Cascade STEM School, Ms. Cruz needed to support all the science teachers in understanding how to plan, facilitate, and assess project-based learning projects that were led by student interest. This was an important instructional strategy that was part of the Tech Foundation model, and it was also imperative to the success of students' extended projects as part of STEM Symposium program. However, Ms. Cruz revealed that she was not supported with the time and resources for professional development that she felt that she needed to bring all of the new teachers into the PBL model. In particular, she noted that Ms. Ly as a novice science teacher and TfA corps member needed extra support in project planning. Ms. Cruz's response to this problem was to develop a document that articulated the work processes involved in supporting students' PBL projects. The document provided a framework and pictorial overview of the process of student project facilitation, with a focus on five phases: project planning, project launch, student learning and project management, project deliverable, and project reflection. Ms. Cruz's creation of tools like this that articulate work processes was one way for her to scaffold the teachers' professional learning without requiring in-depth professional development, for which there was no financial support. This is also an example of an interactional process, in which Ms. Cruz designed a tool to use for persuading and educating the science teachers to engage in PBL teaching practices. Ms. Cruz also developed a PBL handbook for teachers, but worried that without professional development to accompany it, teachers would not use it.

During her second year in the job of project manager/instructional coach, Ms. Cruz attempted to protect herself by limiting her work tasks to the three goals that she set for herself at the beginning of the school year at the merged Cascade STEM School. These goals were: (a) supporting CSP project work, including being involved in the enactment of the biology curriculum unit in Ms. Ly's class; (b) promoting and cultivating a STEM culture on the school campus; and (c) coordinating the STEM Symposium program, scaling it up to accommodate the larger student population at the merged school, and truncating the program's timeline. However, she admitted that it was difficult to balance these different goals, which integrated work tasks and relationships across the foundation, school, and university. She also explained that she unable to meet with the school's new administration team at the beginning of the school year to elicit their feedback and support for her goals, as they were otherwise occupied with launching the merged school. Ms. Cruz reflected that during her first year in her new position, she did not know how to balance all that was expected of her, but that she was trying to enact changes this year to her own processes. She explained,

> Last year, I felt like I was, like disconnected, somewhat disconnected from the [CSP] curriculum. And I think it's because I didn't know what my balance was in terms of your initial question you asked me, how am I balancing everything. I really didn't know how to balance it at that time. This year I feel a lot more comfortable. I've also learned to say no. At [Tech Foundation], I'm staying out of the administration role, staying out of all the meetings and I'm holding on tight to my job and my job only. I'm saying no to everything else that's outside of my three goals. That's been really helpful.

Some of her strategies for articulating her work processes and limiting her responsibilities included reserving one day each week to work at Tech Foundation and attend the CSP weekly planning meeting at the University, rather than spending every work day at the school. She also tried to clearly communicate her goals among her work teams and supervisors to set up clear expectations, especially as she prepared to shift more time to supporting Ms. Ly in the biology unit enactment for several months. Ms. Cruz also began to say no to any asks of her time that were not in alignment with her three work goals in order to hold "on tight to my job and my job only."

However, despite her attempts to balance all of her job tasks, the same theme that ran through Ms. Cruz's experience as a teacher extended to her new role with Tech Foundation. She continued to feel overwhelmed and overworked, and the school merger followed by becoming a new parent at the end of the school year only added to this experience. After taking parental leave for the birth of her child and briefly returning to her position at Tech Foundation, Ms. Cruz realized that she needed a job that was more flexible, that allowed for her to work from home part-time, and that was less stressful. Ms. Cruz described her decision to resign from her position as both “tough” and “bittersweet” after working at the school and foundation for five years. However, Ms. Cruz described Tech Foundation as operating under the notions of “just get it done” and “figure it out”, rather than carefully considering what was going to make the organization efficient and sustainable. Ms. Cruz characterized Tech Foundation as being “need-based”; whenever a need arose, they just found a way to fill it, no matter what. She saw this at STEM Academy when she was asked to teach math in addition to science classes. She experienced this at Tech Foundation when she was asked to take on a huge project with organizing the STEM Symposium, which was “added to her plate” without providing her with additional resources. She also experienced this after the school merger when she was expected to provide coaching and professional development to a swelling group of science and math teachers with diverse needs, without any additional financial resources or personnel. In addition, she consistently engaged in boundary work as she helped to coordinate CSP curriculum enactment activities at the school, attended weekly planning meetings at the university, and kept everyone informed of district, school, and research activities. She took on the roles of project manager, communication liaison, teacher, instructional coach, event planner, committee member, and more as she worked across the interconnected activity systems of district, school, foundation, and university.

Ms. Cruz felt that Tech Foundation was at the very early stages of figuring out how to enact their vision in sustainable ways. She felt this in her CSP work, in that all of these other job responsibilities required by Tech Foundation nibbled away at her capacity to carry out CSP partnership work tasks in the ways that she had hoped. In her last interview, Ms. Cruz noted her regret, "…I wish that I had more time to focus on this [CSP] work, but there's just so much going on and so many other things that need attention, that it wasn't always the priority". This ever-shifting context—from her roles, to changes in district priorities, to the very school itself—made it difficult for Ms. Cruz to ever feel like she had her feet firmly under her even after five combined years with the school and foundation. After leaving Tech Foundation and exiting her role in the CSP, Ms. Cruz transitioned to a new job designing PBL science curriculum at a non-profit educational organization.

This summary captures Ms. Cruz's movement through jobs and roles among the members of the CSP partnership. As this narrative continues, it will be shown how institutional histories and cultures influenced boundaries and shaped Ms. Cruz's approach to her work. Ms. Cruz was asked to engage in complicated articulation work and to work across the boundaries of four institutions. In this way, she did not have a single institutional shelter (Sennet, 1999 as cited in Edwards, 2005; Penuel, Coburn, & Gallager, 2013; Penuel et al., 2015), rather her professional life extended across multiple social worlds, as it existed within both the school and the foundation and required that she engage in articulation across the boundaries of these institutions and the university. The boundaries that Ms. Cruz encountered in this work were influenced by the histories and contexts of each of the institutions in the partnership, which caused these boundaries to change over time. Social Practice Theory's concept of contentious local practice (Holland & Lave, 2009) is relevant here, as it acknowledges that people are situated in institutional, cultural, historical, and political contexts. As Ms. Cruz coordinated work across different social worlds and professional practices, her focus and roles shifted over time, based on what was needed of her. In particular, the school merger represented a significantly disruptive example of how existing boundaries were amplified and new boundaries emerged.

Spanning Boundaries through Relational Collaboration

In this section, I focus on how Ms. Cruz collaborated with the CSP research team. I highlight findings related to how Ms. Cruz engaged in relational forms of collaboration within the CSP and how she articulated interactional alignment across work groups. In general, Ms. Cruz and the researchers developed a productive, collegial, and supportive working relationship. Ms. Cruz was asked to define "collaboration" during four of her five interviews spanning over two years (December 2016-August 2018). Her definitions captured collaboration within the CSP as relational work that included working toward a common goal through distributed expertise. She also noted how the functional collaboration between her and the CSP research team buoyed her confidence about feeling a lack of content expertise during curriculum design and enactment activities.

Working toward a common goal through distributed expertise. When asked to define collaboration, a common theme across Ms. Cruz's interviews was the importance of diverse, distributed expertise across the core members of the CSP partnership: herself, four researchers, and the CSP director. In her initial interview, Ms. Cruz noted, "What I really value with the [CSP] work is having so many different skills at the table" and "I also feel we're all experts in different areas." This distributed expertise created a team that was "well rounded". Ms. Cruz commented, "we each brought our strengths and our skills to the table and that really helped bring the curriculum together." Ms. Cruz noted that it is important in collaboration to have a goal in common, so that "we're each contributing what we can to get there." It is this distributed expertise that allowed each member in the team to contribute in the ways they could to the common goal, with each person taking "on pieces that were accessible to us". She explained her approach was, "if you see a need and you can fill it, fill it." The teams' relational approaches to collaboration and distributed expertise helped the CSP core members engage in joint work toward shared goals at the research-practice boundary.

Ms. Cruz's relational expertise allowed her to identify distinct areas of expertise and skills that each core member of the CSP brought to the partnership and contributed to the joint work. This included the researchers' distributed expertise in educational best practices, curriculum design, assessment design, disciplinary content knowledge, computational thinking, and possessing a teacher's perspective. Ms. Cruz also identified contributed skills of these team members, such as providing project leadership, mentorship, supporting teachers, reviewing documents, communicating, and resourcing her with tools for practitioners. In addition, Ms. Cruz acknowledged the power that the CSP director brought to the table based on his position as a university faculty member and principal investigator of the grant funding the project. When Ms. Cruz arranged meetings between the CSP director and district and school leadership, she noted that she knew the messages about the CSP "would be taken in a different way than it would if it were coming from me", noting that "it was well received" and that these meetings "made the district a little bit more excited" about the project. Ms. Cruz also identified and valued the expertise and contributions of the partner teachers Ms. Eider, Mr. Sherman, and Ms. Ly. In her interviews, Ms. Cruz reflected on the teachers' areas of strength and developing areas of their classroom practice and thought carefully about how to best support them.

Relational aspects of functional collaboration. When thinking about the meaning of collaboration, Ms. Cruz noted that the researchers, teachers, and herself developed a strong sense of respect for each other's expertise and contributions. Even when she was new to the partnership, she felt valued by the research team, noting "…you guys valued my opinion, which was nice. In teaching you don't get that I feel unless you've had a couple years under your belt."

There was power in the emotional effects of this collaboration and she seemed to genuinely enjoy being a CSP collaborator. Ms. Cruz reflected, "…collaboration, to me, is also I think supporting each other and that and again like feeling valued. That's not always something that happens in collaboration and I feel like we equally valued each other in this work."

She also shared, "honestly, I love the people that I work with. You guys [CSP researchers] are so helpful and just no egos. Everybody is willing to help each other when needed. It's awesome."

In addition, Ms. Cruz described other relational aspects of collaboration, including leveraging available resources, being an active listener, problem solving, and compromising. This last point is an important example of how Ms. Cruz's relational agency impacted her own definition of collaboration. Ms. Cruz shared, "I think it's also a compromise, where you see, like, everybody's perspective, and then you come to a decision based on that."

Collaboration helped buoy Ms. Cruz's lack of confidence in her personal expertise. In several of her interviews, Ms. Cruz reflected on how the distributed expertise of the CSP collaboration helped buoy her in areas where she felt a lack of confidence. This first surfaced for her during the design of the chemistry unit that integrated earth/space science concepts, explaining "I noticed I didn't know too much about the earth/space side, but I feel like people within our group were able to pick up and make me feel better about what we were doing because they had a better understanding of it than I did." Ms. Cruz was not as involved with design activities during the development of the chemistry unit in Year One, as she was for the two biology units, but when she was able to participate in chemistry design sessions she was able to leverage content-area and pedagogical expertise in chemistry.

However, it was obvious from her interviews that Ms. Cruz felt some discomfort that biology was not her area of context expertise although a major focus of CSP activities was the design and enactment of two biology curriculum units. Ms. Cruz's undergraduate degree was in chemistry and her teaching experience was focused on high school chemistry and physics courses and middle school general science; she had never taught a biology course.

In preparation for the enactment of the biology evolution unit, Ms. Cruz was asked by the CSP director to develop a co-teaching practice with Ms. Ly to support her, as a second-year teacher, with the enactment. Ms. Cruz developed a practice of co-planning with Ms. Ly, co-teaching one of her biology class sections four days a week, and engaging in regular debriefs of instruction. However, as Ms. Cruz pointed out in an interview, this was an atypical co-teaching model. She explained,

> So yeah, I've never done co-teaching this consistently before, and it didn't necessarily feel like co-teaching, because normally in co-teaching, most co-teaching models, we both know the material, and so we're able to like build off of each other, and build off of each other's statements, and oh, you forgot this part? Oh, don't worry, I'll add it. Well, it couldn't have ... that didn't work in this specific situation, 'cause I didn't know the material as well as she did, so I also had to trust Ms. Ly. She knows her stuff. She's a bio major.

In this case, Ms. Cruz did not have the biology background nor the discipline-specific pedagogical content knowledge to feel confident in the material. Across her five interviews, Ms. Cruz brought up this lack of content expertise seven times. Her language about herself in this context was often self-critical, as these excerpts demonstrate:

> "…not being able to add expertise from the biology area was tough for me this year…
> "…I just think that biology wasn't my strong area, so I don't think I was able to contribute as much."
> "…because I definitely couldn't add there. I didn't take enough biology to be able to add to the content area."
> "…again, I wasn't the expert on the content…"

Being part of a team with diverse forms of expertise allowed Ms. Cruz to feel “okay” that she did not know everything or could not always contribute. However, it is important to consider how positioning Ms. Cruz as a co-teacher within a biology classroom—while offering her an interesting professional learning experience—may not have been in service to the overall CSP project goals. As Ms. Cruz herself described, her co-teaching arrangement was an unusual one in which she did not feel prepared to co-facilitate the content. She also expressed concern that she would step on Ms. Ly’s toes.

At times, Ms. Cruz described her lack of biology content expertise as an asset to the project, explaining that it provided her with a novice lens akin to what students might experience as learners. For example, Ms. Cruz first stated in an interview that, “I know I can't be very helpful with the content” and then modified her statement:

> Although, I guess I can be. Because I'm not familiar with the content, I think that I'm going to be learning along with the kids. So if I'm confused about something, chances are the kids are confused about something. So I can really help with misconceptions, and catch misconceptions, and to determine whether or not students are understanding the content or not.

By positioning her as a co-teacher in Ms. Ly’s classroom, the research team was not expecting Ms. Cruz to have expertise in biology content, as members of the research team possessed that professional expertise. Instead, the hope was that Ms. Cruz would support Ms. Ly in creating a classroom environment in line with the vision for the CSP—one that was student-centered, equitable, and computationally-rich—and guiding local adaptations to the curriculum-as-written. Ms. Cruz seemed to see her role in a different light and focused her co-teaching mostly on assisting Ms. Ly with classroom management. Observations of co-teaching episodes showed Ms. Cruz engaged mostly in the following instructional practices: classroom management (i.e., volume control, keeping students on task), time management (i.e., moving activities along, reminding Ms. Ly of how much time was left in the class period), materials management (i.e., handing out worksheets), and student check-ins (i.e., meeting with a group or individual student, answering questions). Therefore, Ms. Cruz was not providing Ms. Ly with disciplinary specific instructional coaching during co-teaching and co-planning episodes, nor helping her develop an understanding of computational practices, rather she saw a need to help Ms. Ly develop more general practices for teaching.

Ms. Cruz's relational expertise allowed her to recognize the distributed expertise of the CSP team. Ms. Cruz and Ms. Ly developed a collegial relationship (Barth, 2006) in which Ms. Cruz talked about classroom practice and work habits, shared craft knowledge, and offered support. This case shows the value of relational orientations toward collaborative work.

Spanning Boundaries as a Person-in-practice

This section offers a perspective of Ms. Cruz as a person-in-practice within the CSP professional contexts. In her interviews, Ms. Cruz was able to surface the forms of expertise that she leveraged in her CSP work. These areas of expertise included her institutional and insider knowledge, her craft knowledge and pedagogical expertise as a teacher, and her relational expertise, relational agency, and adaptive expertise. Through her CSP experience, Ms. Cruz had a relational view toward collaboration, and was able to identify and align to the expertise of others within the partnership. In addition, the CSP experience presented a learning opportunity for Ms. Cruz to develop different areas of expertise through her engagement in project tasks. Therefore, the CSP became part of her professional learning trajectory. In this section, I consider Ms. Cruz as a person-in-practice within the relationships and boundaries of the CSP partnership and school contexts. I begin by sharing Ms. Cruz's own descriptions of the areas of expertise she brought to her roles.

Institutional and insider knowledge. Ms. Cruz possessed historical institutional knowledge of the school and its district from her three years as a teacher at STEM Academy. She recognized the utility of this knowledge, commenting that, "…I think it's nice to know the complexity of [STEM Academy] and be able to explain what's going on" to the other members of the CSP and to teachers. Ms. Cruz's expertise extended to her insider knowledge unfolding initiatives within the school district, afforded by her participation on two district committees: a science curriculum adoption committee and a NGSS rollout advisory committee. Ms. Cruz explained that it was important to have someone with this type of knowledge in the CSP or partnerships like it:

> And then you need somebody who's familiar with the district that you're working with. Because there are also a lot of requirements from the district that need to be met through the curriculum that, that we're teaching. And so, and, and even like thing—some, dealing with like schedules, that schedules, and I think that was helpful, because I'd been in the district for so long that I can give you a heads up about what was going on.

This insider knowledge of the historical, cultural, and political dimensions of the school and district were helpful to her role within the CSP and her work coaching the science and math teachers. From the perspective of the CSP researchers, Ms. Cruz possessed a depth of insider knowledge that would have been difficult if not impossible to obtain on their own. For example, Ms. Cruz was a member of a science leadership committee that advised the district on plans to roll out NGSS-alignment, a role that would not have been open to the CSP researchers. Ms. Cruz described the committee as, "…just a team of teachers that got together that, we were discussing the next gen standards and then the rollout of the standards, what would be best for our district. So we as a team decided that slow rollout would be best for our teachers and, whereas I think last year was the first year that we fully implemented all of the NGSS standards."

Ms. Cruz recognized that her participation on this committee afforded insider knowledge that was critical to the CSP partnership. She explained, "…and so I knew what was going on in terms of like the NGSS standards and the rollout and how we're doing it." Ms. Cruz's participation in this committee provided her with district-specific insider knowledge that the university researchers were not otherwise privy to. When asked what expertise she brought to the CSP partnership, one thing Ms. Cruz mentioned was this type of insider knowledge, that it was valuable "…just knowing the inner workings of the school district and how it functions." In these ways, Ms. Cruz was engaging in articulation work (Strauss, 1988) in which her insider knowledge functioned to bring the team into interactional alignment so that we could coordinate and align our actions with that of the district.

Ms. Cruz noted that during the initial design meetings for the chemistry unit in Year One, when she was still in her role as a science teacher at STEM Academy, she and Ms. Eider both brought information about the district rollout plan to our design process, which caused the team to shift our focus on how we might integrate earth/space sciences content to meet the district's needs. Ms. Cruz explained in an interview, "At the time, I knew the most about ... 'cause I was attending the NGSS meetings, so I knew what our roll out was gonna look like…So that's when we started talking about the earth space changes that were gonna take place." Ms. Cruz brought critical information from the district to the design table that directly impacted design decisions.

However Ms. Cruz was careful to note that while she had insider knowledge about the district's NGSS rollout plans, her expertise with the NGSS was still developing. She noted, "…it's hard because as a district, we're all grappling with these like new standards and we're again, we're not used to it, like everything is, was new to me". Ms. Cruz understood that her expertise was in a process of development, as she was learning about the NGSS while at the same time advising the district on its rollout plan and coaching STEM Academy science teachers about how to facilitate NGSS-aligned learning. As a member of the CSP, Ms. Cruz engaged in opportunities to deepen her understanding of the NGSS. In interviews, she noted how her participation in CSP afforded opportunities to extend her professional learning through engagement in the design and enactment of NGSS-aligned curriculum materials, and the design and grading of three-dimensional summative assessments that integrated case studies. During planning meetings, Ms. Cruz was also introduced to researcher-developed tools for engaging teachers in professional learning about the NGSS.

Ms. Cruz explained her thinking about the value of this kind of insider knowledge to the CSP and partnerships like it:

> It would be harder to navigate. I think if you didn't have knowledge of you know what happens at the school level or at the university, but it can be learned. But then again, experiences are really powerful. Like that's almost I think about what I'd be able to teach just through theory, just learning about it. I don't know. I definitely did better in practice. So maybe if they were thrown in and they shadowed, I think they could do it without experience.

Ms. Cruz brought to her role her experience not only as a science teacher, but as a teacher at the school and district, as well as a new employee at the partner organization Tech Foundation.

In comparison, the person who held the project manager/instructional coach position before Ms. Cruz in Year One of the CSP was an external hire who had not previously worked for the school, district, organization, or university. His background was as a scholar, thespian, and restorative justice consultant. The person hired into the same role after Ms. Cruz resigned had experience as a science teacher and had completed her graduate program in education at the same university that served as the context for the CSP, as did Ms. Cruz, but did not have prior experience with the school or district. By hiring Ms. Cruz from the teaching faculty at STEM Academy, the Tech Foundation was able to fill this role with someone with a constellation of expertise that included insider knowledge of the organization. However, it should be pointed out that Ms. Cruz had not received specific training in teacher education or instructional coaching to prepare her for this new position, nor did she have expertise in learning sciences which would have possibly benefited shared understandings with the research team.

Craft knowledge and pedagogical expertise. Through both her teacher and coaching roles, Ms. Cruz was observed freely sharing her craft knowledge and pedagogical expertise with the other science teachers. This included strategies for classroom management, advice on developing and facilitating PBL projects, and applying her "teacher eye" during curriculum design activities. Craft knowledge is a form of expertise developed by teachers over the years that they perform and sharpen their craft of classroom practice (Barth, 2006). In her third interview, Ms. Cruz noted that her expertise in PBL was an asset. She commented that she had expertise in facilitating projects and guiding students through projects, including using tools like Exit Tickets and Poll Everywhere to track students' progression through a project. This expertise was leveraged in particular when she realized that many of the new-to-her teachers at the merged Cascade STEM School did not have prior experience with PBL and requested her help with project planning. Ms. Cruz's interviews reveal that she felt that her experiences as a science teacher provided her with a "teacher eye." Goodwin (1994) conceptualizes this as professional vision, which can be thought of as the domain of professional scrutiny or the insignia of a particular profession, such as the theories, artifacts, and areas of expertise that together focus a person's attention within a particular profession. Ms. Cruz applied her professional vision in constructive ways during curriculum design activities, noting that although there had been major changes in approaches to science teaching since her pre-service training at the university, including the adoption of the NGSS, her craft knowledge could be leveraged. Ms. Cruz explained, “I still hold on to things that have worked for my kids.” She saw her “teacher eye” as an asset to the team, stating in her final interview, “I feel like I just saw little things in the curriculum that I was able to add, whether it's a small, you know, improvement or large improvement. I felt like the teacher eye was able to add strength whether small or large.”

Advice networks. An important thing to consider in order to understand Ms. Cruz as a person-in-practice is her own sources of advice, mentorship, and support. As a first year teacher, she developed an important mentoring relationship with her principal. More recently, as she moved into her new position at Tech Foundation, her direct supervisor offered her support, advice, and served as an advocate on her behalf.

When she was a first-year teacher, Ms. Cruz struggled so much with classroom management, she was fearful she would be fired. However, a formal observation by her principal during which she struggled with classroom management transformed into an opportunity for mentorship, which “turned me into a really strong teacher after my first year.” Ms. Cruz explained in an interview, “[my students] just kept going with their normal behavior and it was even worse than usual, to be honest.” The principal took Ms. Cruz “under her wing”, taking on a mentor role in which she presented scenarios to Ms. Cruz and a few other teachers and asked them to role-play what might follow. Ms. Cruz noted, “and then after that, based on what I initially told them I would do within our role playing, they then gave me advice. ‘Well in that situation try doing this. Try doing this. Tell us how it works.’” In her own words, this mentorship experience transformed Ms. Cruz from a struggling first-year teacher into one who had a handle on classroom management. Ms. Cruz noted, “and I mean, that second semester I was one of the model teachers, even.” Ms. Cruz reflected that,

> If you don't have classroom management, nothing ... And everybody says that, you know. With classroom management, everything else will follow. And I was able to actually see

> that firsthand. They're right. Once I had classroom management, everything else kind of fell into place, content as well. Yeah, it was good, really good. So that was my first year.

These early experiences cemented Ms. Cruz's stance on the importance of classroom management—a stance that would later surface during her coaching of Ms. Ly and how she prioritized her time when co-teaching in Ms. Ly's classroom.

During her tenure with Tech Foundation, and important member of her advice network was her direct supervisor. Her supervisor fulfilled multiple functions in Ms. Cruz's professional life, including giving advice, helping her problem solve and navigate challenges, dealing with budgetary duties related to the CSP partnership, and advocating for a lighter workload for her, in particular in terms of the STEM Symposium. Ms. Cruz explained, "he was trying to figure out how to put some of that pressure or some of the burden on our other teams" rather than having the program rest solely with Ms. Cruz. However, his support was short-lived. Ms. Cruz acutely felt the effects of staff turnover at Tech Foundation when her direct supervisor resigned from his position and left the foundation, at which point, she reflected, "everything was kind of just on me". In particular, Ms. Cruz was put in a position in which she had to take over the accounting aspects of the foundation's portion of the CSP, which represented "a learning curve" for her and one more role for her take on.

The CSP as a community of practice provided a source of professional learning for Ms. Cruz, with the researchers become a part of Ms. Cruz's advice network (Bakker-Doyle, 2011). At weekly planning meetings, she asked for advice, support, and resources for specific problems of practice she saw in her coaching role with the teachers or to support her work at the foundation. In addition, the university also may have served a role as a persistent and reliable partner (Donovan, Wigdor & Snow, 2003) given the shifting landscape of STEM Academy and the school merger and the turnover of her direct supervisor.

Relational expertise, relational agency, and adaptive expertise. Ms. Cruz was a reflexive practitioner who approached her work through collaboration and relationship-building. She had a warm, approachable demeanor. She expressed deep care for students, her "babies." As an instructional coach, it was her job to build a mentoring relationship with the science and math teachers. As a project manager, it was also her job to navigate relationships and institutional differences among the partners that made up the CSP, to coordinate subprojects, and to articulate work processes. However, Ms. Cruz had only five years of teaching experience before moving into the role of instructional coach, and teacher education was a new role for her for which she had not received specific training.

An important form of expertise that Ms. Cruz brought to her roles was her ability to build relationships. This included an ability to recognize, leverage, and align to other people's areas of expertise, which Edwards (2012) calls relational expertise. This also included her ability to collaborate with others toward shared goals, which Edwards (2011) calls relational agency. Ms. Cruz demonstrated relational agency through her ability to leverage her own relational expertise to relate to other people, build and nurture productive work relationships, and collaborate with others toward shared goals. In addition, Ms. Cruz also reflected on how she was adaptive with her goals and coaching strategies amidst people's changing needs, which can be thought of as adaptive expertise. Ms. Cruz felt that these relational approaches helped her to be successful in her job and her work with the CSP.

When asked during her final interview to describe the expertise that she brought to the partnership, one area that Ms. Cruz identified was this relational approach, noting*:*

> …another strength that I brought was the fact that I easily form relationships, so I was able to connect with our teachers that we worked with and identify their needs and also calm them when they needed to relax, or if they were thinking too deeply or putting too much strain on themselves. So I'd say as a mentor I felt like I did a really good job.

Throughout her interviews, Ms. Cruz's discourse describing her coaching role with the science and math teachers demonstrated a relational approach to her work at STEM Academy and Cascadia STEM School.

Ms. Cruz described her ability to support the teachers not only in pedagogical ways, but also including supporting their emotional needs, identifying their needs, calming them, attempting to reduce their stress, and building their confidence. We saw this in particular with the care she showed toward Ms. Eider, a science teacher who faced health issues and ultimately left her teaching position at STEM Academy. We also saw this relational approach to how Ms. Cruz built a coaching relationship with Ms. Ly and felt like it was her personal duty to advocate for the young teachers at the school.

Ms. Cruz herself experienced what it was like to teach a different class each year, with no provided curriculum, and to also be asked to take on math classes in addition to her science course load. This personal experience may have fueled Ms. Cruz's sense of advocacy for the teachers. Ms. Cruz encouraged the science teachers to stand up for themselves to the administration and refuse to teach outside of their certification. She elaborated,

> But I told the teachers, stand firm. If that's what you need, they need to figure out how to give you what you need. They're ... 'cause we value them. We don't want to lose them. And if that's what they need that's what they need.

In her unique role in the project, spanning the school and the educational organization that co-managed the school, Ms. Cruz assumed the role of advocate for the teachers. She reflected,

> So, teachers need to stand firm on what they want. The school will figure out how to keep you if they want you enough. So I'm gonna advocate for them. Whatever they need moving forward, I'm gonna help the [Tech Foundation] side process it and try and figure out how to meet their needs. Because I love our teachers.

Ms. Cruz saw her position as affording her with the power, voice, and position to advocate for the teachers on issues that they themselves may have had difficulty negotiating on their own, noting that it can be difficult for teachers to advocate for themselves to the administration and put them in a vulnerable position. Shifting from the classroom to this new role afford Ms. Cruz a different perspective, in which she realized that teachers may have more power than they realize. “I don't think teachers do that enough. They don't think that they have the luxury of demanding those things because of our contracts and the logistics, even though we do.”

Across her four interviews, Ms. Cruz emphasized how she built relationships with the science and math teachers, developed an understanding of their needs, and supported them in ways that were reflexive to their needs as she best understood them. This is an example of her adaptive expertise and her ability to pivot in reflexive ways, “on the fly”. For example, in her first interview, Ms. Cruz notes that she was meeting with most of the science teachers at STEM Academy once per week at the time, explaining “I still get to observe the teachers, I get to meet with them, ask them their needs and try and meet their needs on the fly.”

After the opening of the merged Cascade STEM School, Ms. Cruz was challenged to build relationships and conduct needs assessments with the math and science teachers who were new to her. In her second interview held a few weeks after the launch of the merged school, Ms. Cruz stated that one of her goals for that year was “to figure out what level our teachers are at; because so many teachers are new in my eyes, I can't just based on experience make those calls anymore like I used to be able to.” As she got to know these new-to-her teachers, Ms. Cruz realized the importance of supporting their understanding of NGSS and project-based learning. When interviewed one month later, Ms. Cruz revealed that she had discovered that these teachers were new to the NGSS and PBL, and needed a level of support she had not anticipated. She explained, “Another shift this year in my work is, I'm noticing that because we do have a lot of new teachers, new to project-based learning, I'm getting requests to actually sit in with them and plan a project with them from start to finish, which is not what my role had entailed, but I'm having to fill this need.”

Later, Ms. Cruz captured her ability to identify and respond to the teachers’ needs—her adaptive expertise—during her final interview, when she reflected back on some of the rippling effects caused by there being so much changes and shifts during the three years of the CSP. She reflected,

> I also feel like you need someone who's adaptive. There were a lot of changes that took place throughout [the] three-year curriculum development sequence. Because each year we did different things due to movement and last year, my role was a lot different than this year. And so I had to really figure out, well one, create relationships with our teachers that we worked with. So you need somebody who can do that. Two, figure out once you've created the relationship, figure out what the needs are in supporting this type [of] work. And then coming up with a way to support those teachers with the needs that they express.

Ms. Cruz’s relational expertise and relational agency allowed her to build collaborative, cross-practice relationships (Edwards (2011, 2012).

As Ms. Cruz deepened her coaching relationship with Ms. Ly, she identified ways in which she felt she could best support this novice teacher. In particular, Ms. Cruz focused on helping Ms. Ly develop core teacher practices (McDonald, Kazemi, & Kavanagh, 2013) such as classroom management, timing of activities, grading practices, and differentiation. A particular practice that she focused on, one that is critical for PBL instruction, was helping Ms. Ly develop strategies for student grouping and facilitating group work. However, as the vignette below demonstrates, a difference in approach between Ms. Cruz and the research team arose as a potential threat to our relational alignment.

The Team Contract as a threat to relational alignment. A critical incident occurred during the enactment of the biology unit in Ms. Ly's classroom which serves as an example of a challenge to Ms. Cruz's boundary spanning abilities. The incident caused the researchers to question their assumptions about being in alignment with Ms. Cruz about a shared stance and approach toward PBL and equitable classroom instruction. It surfaced questions about Ms. Cruz's own relational stance to students and her attitudes toward classroom management strategies. This incident represented a disruption to CSP classroom enactment activities and threatened the relational alignment between researchers and Ms. Cruz. Leading up to this incident, myself and another member of the CSP research team had noted during classroom observations that Ms. Ly struggled with classroom management and differentiation of instruction. She was also encountering microaggressions from particular students in her biology classes. For example, one student, whose classroom behavior shifted from class clown to a more aggressive and antagonistic tone as the weeks went by, was overhead making racially-charged comments toward Ms. Ly.

About a month into Ms. Ly's enactment of the biology unit as students began working on the culminating project for the unit, Ms. Cruz introduced a tool that she thought would help Ms. Ly facilitate project work among groups of students and hold students accountable to one another. Ms. Cruz called this a team contract, an agreement among members of each student group that sets up shared expectations. Ms. Cruz first mentioned the tool on a Friday afternoon during one of our regular post-instructional debriefs. When I was later able to review an online version of the contract that she and Ms. Ly had developed, I was concerned by the language and spirit of the document. The contract included a three-strikes clause that would allow group members to issue strikes against a teammate for not meeting expectations, ultimately allowing the team to vote the member out of the group. When I was able to review an online version of the contract, I was concerned by the language used in the document and the three-strikes clause. The document used terms like “violated”, “intervention”, “breaks the rules” and “vote out that member.” The other members of the research team shared my concerns when I brought it to their attention and we felt that the document should not be used with students without major revisions. *Appendix F* shows Ms. Cruz’s original Project Team Contract. Another researcher and myself left comments on the online document, to which both Ms. Ly and Ms. Cruz replied. Ms. Ly agreed with our suggestions to focus on more productive and relational ways of ensuring teams were working well together and meeting timelines, such as meetings with the team mediated by the teacher and the use of survey tools to elicit regular check-ins on team dynamics. Ms. Cruz suggested that the second page that outlined violations and interventions was not needed. We requested that Ms. Ly delay using the contract until the research team could develop some alternative approaches over the weekend. Ms. Ly agreed to wait and began working on developing a spreadsheet that would allow individuals and teams to provide daily check-ins on their progress.

The research team was deeply concerned that this tool represented an inequitable approach to learning. It positioned students in the role of disciplining their own peers. It risked having popularity or other factors influence who is allowed to stay and who is voted off of teams. It could result in the isolation and embarrassment of students in a public way, which could cause the penalized student to further disengage from their peers and their class work. The contract also did not include any reentry plans for a student who was voted off of their team. Without having had the opportunity to see how this type of contract had unfolded in Ms. Cruz’s classroom in the past, the researchers were left to imagine how it may play out in Ms. Ly’s classroom.

The following week, I had a quick hallway conversation with Ms. Cruz and Ms. Ly after observing instruction. Ms. Cruz said that she agreed with the researchers' comments about the language used in the contract, and that "warning" would be a better term than "strike." She also noted that if a warning was issued by teammates to a student, then the teacher should meet with the team and with the individual student. At our project planning meeting that afternoon, which Ms. Cruz was unable to attend, I worked with the other members of the research team to develop alternative options to the contract, and to collect resources related to differentiation strategies, accountability, and team work within PBL to share back with Ms. Cruz and Ms. Ly. We also developed a survey construct that Ms. Ly could use with students that focused on PBL problem work and team dynamics.

My own researcher memo written on that day was a collection of worries. I noted that the proposal of using the team contract surfaced for me concerns that had been bubbling throughout my observations of the unit enactment in Ms. Ly's classrooms. I wondered about what were the barriers to PBL, as the research team conceived of it, at the school and in Ms. Ly's classroom. I wondered why Ms. Ly was launching the unit project so late when the curriculum specifically intended for it to be launched at the beginning of the unit and returned to at regular intervals throughout the extended unit. I wondered what conceptual model Ms. Cruz held of PBL, and how that aligned or differed from that of the research team. I worried over the emphasis on classroom management, overly scaffolded instruction, and slowing pace of instruction was acting to disengage students from the course and content, leading to students' expressions of fatigue with the featured phenomenon in the unit. I felt concerned by the deficit-framing of students that I had observed, and felt that the team contract with its focus on accountability and positioning peers as disciplinarians was a symptom of this.

Ms. Ly decided to implement a revised version of the Project Team Contract with her students, as shown in *Appendix F*, along with other tools to track individual students' and teams' progression with the unit project. The revised contract included changes in language, and removed the three-strikes clause. It also eliminated the table in the second page that outlined violations and interventions. Ms. Cruz continued to defend the contract on several occasions, noting that it had worked well for her in her own classroom as a tool for accountability. I felt a disconnect between Ms. Cruz's defense of the contract as a pedagogical tool and the researchers' concerns about inequitable instruction that underpinned it.

One week after Ms. Cruz introduced the Project Team Contract tool, I attended a debrief session that further raised my concerns about the teacher's deficit-framing of students and their difficulty facilitating PBL at the school. On this day, Ms. Ly and Ms. Cruz chose to use our scheduled debrief time to meet with an instructional aide who had begun helping out with Ms. Ly's first period class, the ninth-grade humanities teacher, and the ninth-grade math teacher. The meeting began as a way to think productively together about strategies for grouping students for project work in the biology unit, as Ms. Cruz and Ms. Ly were struggling with how to honor students' own interests in the different project roles available to them (i.e., oceanographer, geneticist, population biologist, and geographer) while balancing their concern for which students did and did not work well together. They also wanted to develop a plan for how the instructional aide could best support Ms. Ly and her students. As the team contract issue had shown, Ms. Cruz and Ms. Ly felt that they needed to think carefully about student groupings in order to make the extended project work for the biology enactment successful. However, the meeting quickly devolved into an exchange in which the teachers talked about individual students, with a strongly deficit lens of student ability, with a focus on what students wouldn't and couldn't do. The conversation surfaced pedagogical strategies that I felt were problematic, such as choosing student groupings that would position higher-achieving students as disciplinarians and babysitters to their lower-performing peers, and an overall difficulty in providing differentiation for students at widely varying abilities. The conversation also showed how these teachers were struggling to facilitate PBL projects in equitable and student-centered ways, though the Tech Foundation's award-winning vision prioritized PBL STEM learning as one of its foundational approaches. The teachers expressed their own challenges with knowing how to group students for project work, build in accountability structures, and deliver project instructions. Ms. Cruz and Ms. Ly seemed to support another teacher's model of breaking project work into phases and not allowing teams to move forward if a group member had not finished their work for that phase, even though they acknowledged that this approach seemed to waste instructional time, slow the pace of project work, and penalize students who completed their work on time. Like the Project Team Contract showed, these teachers were facing challenges in almost all aspects of facilitating student projects in a PBL model.

This teacher meeting extended for one and a half hours and left me feeling concerned about teachers' deficit-framing of students, inequitable classroom practices, and difficulty with differentiation and facilitating student projects. After consulting with the other members of the research team, we decided to share some of our observations with Ms. Cruz at our upcoming CSP weekly team planning meeting. The research team worried that this meeting could mark a pivotal moment in our relationship with Ms. Cruz and by proxy Ms. Ly and thought carefully about how to surface our concerns.

During the next weekly CSP meeting, the researchers shared with Ms. Cruz some of our recent observations of Ms. Ly's biology classes. During the meeting, Ms. Cruz seemed open to the conversation and often in agreement with many of our observations. While the researchers felt that it was important to share their observations, they also acknowledged the risk that the conversation might feel like a judgement on Ms. Ly's teaching practice or Ms. Cruz's coaching skills. We talked about strategies to support Ms. Ly and her students, and also spent some time thinking together about particular students. We had a shared concern if the school administration was supporting Ms. Ly enough given multiple instances of microaggressions in her classroom.

The researchers were not privy to the ways in which Ms. Cruz later translated this conversation to Ms. Ly, however we did see some shifts in Ms. Ly's teaching practice when she employed new talk strategies for small group discussion with her students and when she employed a self-assessment tool and also leveraged the other adults in the room to help with tracking student participation in an activity, rather than positioning students as responsible for grading their peers. After the meeting, Ms. Cruz prepared an online documentation to assist in her coaching with Ms. Ly, inviting the research team to help think with her in the document about strategies Ms. Ly could employ with particular students. One of my research colleagues contributed to the document, providing general strategies and particular thoughts on students' particular situations. It is interesting to point out that here, again, the research team was engaged in providing basic types of support to Ms. Ly and Ms. Cruz in order to help Ms. Ly manage her classroom, illustrating the types of needs Ms. Ly had as a second-year TfA corps member. It is also important to note that by being a core member of the CSP partnership, Ms. Cruz was able to ask for and receive advice from researchers to help her broaden her perspectives on equitable classroom strategies and coaching strategies.

About a month after Ms. Cruz had originally championed the Project Team Contract, Ms. Cruz again brought up the contract in conversation during a debrief session with Ms. Ly and myself. In this conversation, she asserted that the contract was an effective tool in her experience for managing PBL projects when one group member lagged behind the others, holding up the team's progress. The concern she and Ms. Ly were discussing was how higher-achieving students were likely to take over the work tasks of the lower-achieving student, and how this caused stress on those students. Ultimately, each person on a team was supposed to be analyzing data in order to contribute a data visualization to an infographic on Sea Star Wasting Disease that the team would create and present collaboratively. Ms. Cruz said, "And that's why I, I know it probably seemed harsh, but that's why I brought up the firing system because that happens so often and gives other kids anxiety. And they end up doing more work than they're supposed to, which stresses them out in other classes. That's why I went to that system…" Ms. Cruz noted that the idea for the team contract originally came from another science teacher at a different school. She explained how the contract worked for her in her own classroom:

> Ms. Cruz: And to be honest, I never had to fire anyone. But just having that there, as a consequence to the work, having them tell me that their group member had a strike, brought on a conversation that helped me understand where the problems in the group lied and what extra supports they needed from me. And what oftentimes would end up happening was I would get down to the, I would figure out what the root problem was for one kid, and I was like, oh, it's just too much. And so what I would end up doing is figuring out a way within their individual role to lessen the demand. And like, if I had them look up four resources, I would narrow it down to two. If I had them doing like, specific—for physics I had them doing specific math problems to show things, I gave them less. Like so it was, like, even though they got strikes along the way—
>
> Ms. Ly: They never get to the three.
>
> Ms. Cruz: They never got to the firing piece. Because it never needed to go that far. Now there are teachers who have gotten to that point. I've never.

Ms. Cruz emphasized that she had never gotten to the point where students "fired" a member of their group, explaining how she used the contract as a tool to surface problems with group dynamics so that she could get to the "root problem." She continued to explain how it was important to develop “alternative pathways for the kids” for students that may be “voted out of their group” and how she met with the special education team to develop those options. Ms. Cruz continued by explaining how she felt that this arrangement worked with her students “because I was close enough with my kids.” She also explained that she couched the contract with her students as being authentic to their future lives, and that it was modeling real world consequences, stating, “…in the real world you would get fired if you weren’t doing your work.”

Although we had multiple conversations about what the researchers found problematic about the team contract, Ms. Cruz did not view it as inequitable to students. It is possible that when played out in her own classroom in which she had existing relationships with her students, the contract did not have the impacts that the researchers imagined. However, during this exchange I tried to work toward consensus by offering suggestions on alternative ways of solving the team dynamic problem that did not rely on the firing of a team mate. I first noted that the conversation had begun with Ms. Cruz and Ms. Ly talking about specific students who were struggling to keep up with the project tasks and how this was affecting their group members and observed that they knew which teams and individuals were struggling without needing the contract as the tool to gather that information. They knew this through their check-ins with groups and conversations with students. I offered the observation that they knew this without having to have anyone kicked off of a team, and that we could employ Ms. Cruz’s ideas for alternative pathways in a different way. My suggestions follow:

> Kristen**:** So like one thing would be, if you know, this person is really not going to get their component ready, and they are embarrassed to present their infographic with something missing on it, then you could have the option of actually giving it to the team, giving them that data, if you have the data, or do the analysis really quickly, giving them the data that is missing—

> Ms. Cruz: That works.
>
> Kristen: --and saying, you know, you are going to be graded on your performance, which was poor, you didn't meet the metrics for this unit and that will be reflected in your grade, but I'm going to give you this chunk so your team can now put the infographic together.
>
> Ms. Cruz: See, yes, I love that! So then they know at least that there is support there. We don't have to fill in, we don't have to do twice as much work just to finish our infographic—
>
> Kristen: Right, they don't have to do each other's work.
>
> Ms. Cruz: --Yeah, because that's where they get overly stressed. It's just too much.
>
> Ms. Ly: I had a kid email me at one in the morning because she was doing someone else's job.
>
> Ms. Cruz: Yeah.
>
> Kristen: And I was one of those students who would do that on a team.
>
> Ms. Cruz: Me too.
>
> [Overtalk by all three, agreement]
>
> Kristen: So part of it might be, like clearly communicating how they are going to be graded on this. So—
>
> Ms. Ly: At the very beginning, at the very beginning…

The full transcript excerpt from this debrief meeting shows an arc in which we come to agreement about alternative ways of managing team projects without the use of the team contract, as an example of how our relational agency and collegial relationship allowed us to negotiate through this incident. This conversation continued as we collaboratively developed ideas for how assign individual and group grades for the project work.

As a result of this conversation, Ms. Ly developed three grading tools to collect assessment data to assign individual project grades and team grades, one of which asked student teams to work together to agree which team members had contributed to which project tasks. At the time, the other members of the research team and I were concerned that our pushback on Ms. Cruz's contract and our questioning of her strategies as inequitable might threaten our productive work relationship. However, we were able to move through this experience, listen to one another, and develop new and modified tools for instruction and assessment.

Though these episodes did not fracture our relationship with Ms. Cruz, they did cause the research team to question if we were in alignment with Ms. Cruz as far as our stances toward science teaching and learning. In conversations between researchers that followed these experiences—my observation of the teacher meeting on student grouping, our negotiation of the team contract, and the planning meeting in which researchers shared their observations—we expressed concern that we had made assumptions about what we thought was our shared vision and approach to the CSP partnership work with Ms. Cruz. We did have a shared vision at a general level, but what were the nuances between the ways that the research team and Ms. Cruz were thinking about PBL, NGSS-aligned instruction, phenomenon-based instruction, and equitable classroom strategies? How did our different institutional histories (university and school) shape the nuances in our vision? Had we assumed that Ms. Cruz's involvement in the CSP would lead us to a similar vision, without developing enough opportunities for shared learning together? For example, during the meeting I observed among Ms. Ly, Ms. Cruz, the instructional aide, and math and humanities teachers, there was a moment when Ms. Cruz suggested that the culminating product of the biology unit's project work—a collaboratively generated infographic that highlighted each team member's data findings and visualizations—was not very engaging for students and instead they could substitute it for something more creative, like a newscast. At this point in the meeting, I reminded Ms. Cruz and the other teachers that the CSP was focused on helping students to develop computational practices within the science classroom, something that a newscast skit would not accomplish. In my researcher memo written that day, I captured some of these growing concerns, wondering: “Is school culture trumping the unit?” This is an example of a value tension between what mattered for the CSP as a project and what mattered to the teachers at the school. These experiences served to remind us of the history-in-persons (Holland & Lave, 2009), or the way that history is brought into the present through relations between people and the histories that they represent.

With all of her job responsibilities and shifting roles, we realized that Ms. Cruz had not had the opportunity to dig into understanding our computational framework in the same ways we had as researchers, nor had she the expertise nor the time to fully invest in understanding the biology curriculum. Neither had the research team dug in to fully understand the Tech Foundation’s model of PBL, Ms. Cruz’s own conceptions of PBL, and her ability help Ms. Ly develop her practice until we saw it all unfold in Ms. Ly’s classroom. In an interview that occurred months after the team contract conversations, when asked to define collaboration within the CSP, Ms. Cruz focused her response on not feeling like an expert, being in a state of continual learning, and questioning at times her contributions, noting “sometimes I just felt like I didn’t have as much to add as I would have wanted” and “sometimes I questioned, is it really my place to add or to question that…” There appeared to be a lack of common knowledge (Edwards, 2012) developed between Ms. Cruz and the researchers.

We questioned how we could have better supported Ms. Cruz’s own professional learning in these areas, what practices we could have intentionally developed for shared learning together, and how we could have better surfaced her vision and our own to bring them more closely in alignment. Engaging in collaborative design work—without developing intentional practices for shared learning—did not appear to provide sufficient opportunities for professional learning for all members of the CSP partnership. We also wondered if there was an issue of translation (Edwards, 2012) between the intent of the curriculum as written, the content of conversations in our planning meetings, and how Ms. Cruz translated this information to Ms. Ly through her coaching practice. These concerns represent professional boundaries between Ms. Ly and the researchers, which all served as barriers to Ms. Cruz's ability to span boundaries between the researchers and Ms. Ly.

We also questioned whether STEM Academy and Cascade STEM School were appropriate partners and contexts for the CSP research endeavor, in particular how a second-year teacher was selected to engage in the CSP work, and the structural issues introduced by the school merger. We questioned whether Ms. Cruz had the alignment of vision and coaching expertise to help her support Ms. Ly in ways that were productive for the partnership, not just for developing Ms. Ly's teaching practice. We wondered whether Ms. Ly's instructional choices and major adaptations to the curriculum during enactment provided the insights we need about the curriculum-as-written, even with the CSP's support for local adaptation. For example, Ms. Ly employed major adaptations to the curriculum written that the research team felt significantly impacted the spirit of the curriculum. This included Ms. Ly's reliance on didactic teaching through lectures to pre-teach information, the reinforcement of initiate-response-evaluate (IRE) patterns of teacher-led classroom discourse, a consistent approach to pre-teaching skills and vocabulary rather than engaging students in scientific practices in the context of classroom sense-making, developing highly scaffolded handouts for students in an attempt to support lower-performing students, and a significant delay in launching the project with students. Ms. Ly also engaged in significant micro-adaptation between how she delivered instruction to her first and third period classes, with a deficit-framing of her first period students leading to a slowing of the pace of instruction and an even higher reliance on scaffolds and didactic instruction. Ms. Ly's enactment of the unit stretched it to ten weeks, though as written it was intended to only extend for six weeks of classroom instruction. The research team questioned what was possible and reasonable within the scope of the CSP grant, as our original focus on strategies for collaborative design and engaging students in computational practices within science classrooms significantly shifted to supporting a novice teacher in developing her teaching practice, as a pragmatic constraint of the structural circumstance. (See Chapter Four for additional analysis of early-career teacher involvement in the CSP).

Learning through partnership: Ms. Cruz's professional learning trajectory. Across her interviews, it became apparent that another role that Ms. Cruz took on through her CSP work was that of a learner. In her interviews, Ms. Cruz reflected on how her participation in the CSP partnership provided professional learning opportunities for developing new forms of professional expertise that she likely would not have had access to outside of the CSP. This included her developing expertise with the NGSS, as already described, as well as with computational thinking and curriculum design.

In an interview, Ms. Cruz reflected on how the CSP experience expanded her definitions of "computing" and "computational thinking. It is important to note that although Ms. Cruz revealed an expansion of her understanding of computational thinking during these interviews, she focused only on programming, modeling, and simulation practices. As transcript excerpts show, she did not talk about the other dimensions that made up the CSP computational thinking framework and were a focus of the two biology curriculum units: data practices and systems thinking. Ms. Cruz's interview responses show that Ms. Cruz possibly did not develop a full grasp of the CSP computational framework, which likely impacted her ability to coach Ms. Ly in how to engage students in these CT practices. Ms. Cruz may not have developed common knowledge about CT as the researchers had assumed. This generally speaks to the complexity of taking up a multi-faceted view of computing and computational thinking.

Ms. Cruz also expressed in interviews that she developed expertise in curriculum design through the CSP experience, which helped position her well for the next job to which she transitioned. Ms. Cruz brought to her role prior experiences with curriculum design. At another middle school she worked at previously, she engaged in weekly session of collaborative curriculum design with her grade-level team in which they split up the work, with each teacher drafting an instructional plan for one day of the upcoming week. At STEM Academy, Ms. Cruz had to develop the curriculum for the science courses she taught, where her approach was mostly leveraging existing resources that she found online and adapting them to fit the needs of the school and her students. At STEM Academy, she also collaborated with math and humanities teachers to develop interdisciplinary PBL projects. In addition, I had mentored Ms. Cruz in curriculum design during her experience with the engineering research summer program. As part of that program, she collaborated with other science teachers to design a curriculum unit that was later published and made available online. Interestingly Ms. Cruz did not seem to acknowledge the applicability of these previous experiences, as she described herself as “self taught” and not having experience with curriculum design. Ms. Cruz elaborated, “I feel like I would have benefited from having experience with curriculum design because I did feel lost when I first came in [to the CSP]” and noted “I do feel like I would have been more of an asset had I known or had I had experienced curriculum writing, because I'm self-taught”. It appeared that although Ms. Cruz was able to identify specific prior experiences with curriculum design, she was not counting these as being applicable to the kind of curriculum design we engaged in through the

CSP, perhaps because this was curriculum design for local use rather than the design of materials meant to be published and disseminated broadly, because the design activities were more organic and teacher-led, rather than being part of a formal partnership or initiative, or perhaps because she was "self-taught" and learned through practice rather than having formal academic training specific to curriculum design. Here, she frames her own experience with curriculum design as less valuable as that of the researchers.

However, Ms. Cruz felt like the CSP provided her with learning opportunities related to curriculum design that were important to her professional career trajectory. When Ms. Cruz resigned from her position with Tech Foundation in Year Three of the project, she transitioned to a new job designing PBL science curricula for a non-profit educational organization that some members of the research team had helped launch several years earlier. In particular, Ms. Cruz identified the collaborative nature of curriculum design activities within the CSP as being a valuable learning experience that she would bring with her to her next position, in which she would likely develop curriculum as part of a team. Ms. Cruz reflected on the value of this experience:

> I also got to just see like how, just by watching [a CSP researcher] write the Sea Star Wasting project. It gave me insight on what my future projects could look like. Although I've written my own projects before, it was interesting to see what had come from, you know, collaborative projects. I feel like it worked with like multiple people on coming up with the curriculum that exists. So I, I, just watching I feel like I got to learn like a new format.

As she prepared to transition to her next position as a curriculum writer, Ms. Cruz felt that the curriculum design activities within the CSP increased her confidence as a curriculum writer. Ms. Cruz identified other ways in which her curriculum design expertise developed through her CSP experience. This included learning how to integrate case studies, seeing different formats for summative assessments, being exposed to specific learning activities for students, and thinking critically about how to engage students of color in computational practices.

In addition, her CSP experience afforded Ms. Cruz the opportunity to observe a participatory stance toward curriculum enactment rather than the school district's fidelity perspective. She described the district's approach of adopting a common curriculum to be enacted by teachers with fidelity. In her third interview, Ms. Cruz compared her experience with the district's science curriculum adoption process with the CSP's approach to curriculum co-design. As a member of the district curriculum adoption committee and a science instructional coach, she expressed a preference for the CSP co-design approach over the district's approach. She stated, "I wish that what happened here was more of what happened at school, 'cause I'm starting to learn how districts function, and it's a little disheartening". Ms. Cruz explained that our collaborative approaches to curriculum design were different in both priority and approach. She explained,

> Like the work that we do here, we're always thinking about the kids' best interests. I'm not saying that the districts don't do that, it's just ... you guys are all about adaption, flexibility, like meeting teachers where they're at, supporting them. It's like when you throw curriculum at a teacher, that's not what you're doing. Like we're adapting as we go to get there.

In comparison to the CSP model, she explained, "we have a district that's so large they can't think like that, they have to think from a top down model". She saw the district's perspective on curriculum adoption as "teach it and don't question it, is kind of the way it's left" whereas the CSP approach offered something different. She elaborated, "being part of this team, I see it, you guys are adapting, same with the teachers' needs, thinking about everyone's interests. It's just so nice, it's refreshing". Ms. Cruz described the CSP approach as offering teachers "freedom," recognizing value in approaches to curriculum adoption that promote local adaptation as a best practice. As Ms. Cruz transitioned to her next job as a curriculum writer, she would possibly be able to bring both of these perspectives to her work.

Navigating Structural Boundaries within a Partner Institution at a Critical Time

With an understanding of Ms. Cruz as a person-in-practice in the CSP partnership, how she helped to span boundaries between institutions in the CSP, and barriers to that work, I next share how Ms. Cruz engaged in boundary spanning within one institution at a critical time. The opening of the merged Cascade STEM School at the beginning of Year Three of the CSP represented a major disruption to Ms. Cruz's ability to engage in her work and carry out her partnership tasks. However, it was Ms. Cruz's boundary spanning abilities that allowed the CSP team to continue its work despite the shifting and complex school environment. At the beginning of the school year as Cascade STEM School launched, Ms. Cruz identified three major goals she has set for herself: prioritizing the CSP partnership work with a focus on supporting the enactment of the two biology units; promoting and cultivating a STEM culture on the school's campus; and scaling up the size and scope of the STEM Symposium program at the school. However, just a month later, Ms. Cruz was beginning to feel the stress of the school merger as her goals slipped away to practical realities. Examining the work goals that Ms. Cruz set up for herself at the beginning of the school year presents an opportunity to illustrate some of the barriers and challenges introduced and amplified by the school merger.

For her first goal, Ms. Cruz planned to prioritize her CSP work, with an emphasis on supporting the enactment of a biology unit in the classroom "more head-on" than she had with the chemistry unit the previous year. Ms. Cruz was asked by the CSP project director to support Ms. Ly during enactment through the use of co-teaching. Ms. Cruz expressed excitement at having the opportunity to be "a lot closer to the work" in this way. She also noted that she was able to carve out this dedicated time for supporting the unit enactment from her busy work schedule by clearly setting up expectations at Tech Foundation and the school and minimizing her participation in meetings and administrative tasks.

At this point, Ms. Cruz continued to note the value of her role as a communication liaison between the different members of the CSP partnership, in a way that was amplified as we planned for the enactment of the biology unit in Ms. Ly's classroom. She noted her communication role in helping to keep Ms. Ly informed, "helping to streamline information, like, to disseminate information to her, keep her in the loop". Ms. Ly also recognized the value of this role, and identified Ms. Cruz in her initial interview as "the liaison between the [university] group and me and the kid[s]" and that having Ms. Cruz in that role is "something I'm really happy about."

Ms. Cruz's second goal at the beginning of the school year was "to promote and cultivate a STEM culture on campus." She planned to develop this STEM culture through connecting students with STEM professionals when engaged in project work and by providing NGSS support to the science teachers on campus. Her approach to working with the math and science teachers highlighted her relational approach and included "keeping good rapport with the teachers and letting them know that I'm available at any time." However, a month later, the realities of the school merger had impacted her ability to carry out this goal and caused a shift in her tasks. Ms. Cruz realized that given that the district had fully implemented the NGSS standards after a period of rolling implementation, all teachers needed more support in planning and teaching NGSS-aligned instruction than she had anticipated. Coupled with that, she realized that the teachers from the former Cascade School and new-hires were unfamiliar with the Tech Foundation model of PBL and needed significant support in planning and carrying out projects.

These needs, in turn, trumped her goal of cultivating a STEM culture on campus through developing partnerships with STEM professionals. Ms. Cruz was planning on “moving away from doing the nitty-gritty everyday planning” with the math and science teachers. However, she quickly came to realize “that's not the need right now. The need is, like, starting from the beginning” which entailed her sitting down with teachers and planning projects together. This is an example of Ms. Cruz’s adaptive expertise and ability to be responsive and fluid with her plans.

Ms. Cruz’s third goal was to scale up the size and scope of the annual STEM Symposium event, growing it to include more than double the number of students while shrinking the timeline from four months to one and a half months. However, she quickly began to encounter barriers to this work. She noted in October that the school administration was not providing her with any additional financial or human resources or time for her to train teachers who were new to the STEM Symposium model. This situation inspired Ms. Cruz to be creative in how she articulated work processes (such as the PBL Framework and teacher handbook described earlier), developed relationships with the science teachers, and coordinated a large, school-wide event.

I have provided earlier examples of some of the complications of the unit enactment as far as Ms. Ly and Ms. Cruz’s adaptations and instructional strategies in the biology classroom. In this section, I focus on the bigger picture, moving from the biology classroom to school-wide issues. Chapter One provided background information about the school merger, but here I highlight some of these barriers to Ms. Cruz and the CSP team’s work. *Appendix E* provides a summary of the boundaries specifically related to the school merger in Year Three and identifies the boundary practices and boundary objects that Ms. Cruz used to support joint work across these boundaries. These identified boundaries include institutional, sociocultural, and professional differences between the school and district and within the school building, as highlighted below:

- **Institutional differences between the district and the school:** The district issued layers of mandates that STEM Academy had been immune to in its former state before the merger.
- **Institutional differences between Ms. Cruz and the new administration team:** The new leadership team was inaccessible to her as the new school launched.
- **Professional differences among teachers**: There were differences in professional expertise and work practices among teachers from both schools and newly hired teachers.
- **Sociocultural differences between teachers and students:** Teachers needed to build relationships with new-to-them students.
- **Sociocultural differences between students:** A cultural divide existed between former Cascade School and former STEM Academy students.

The school merger represented a disruption to Ms. Cruz's own work and to the collaborative work processes of the CSP, but Ms. Cruz's navigation through these new challenges was what allowed the CSP work to continue. Without Ms. Cruz's navigation of the boundaries caused and amplified by the merger, it is uncertain how supported Ms. Ly would have felt while teaching the new biology unit in her classroom at the new school, if the researchers would have been able to coordinate their data collection activities, or even if the school's new administration team would have supported CSP efforts on their campus.

An (Im)permeable Boundary Between Research and Practice

As has been described, Ms. Cruz had access to and assumed many porous role categories. However, Ms. Cruz shared that CSP research activities and researcher roles felt less available to her, in that the boundary between research and practice felt impermeable. In her final interview, Ms. Cruz described this as a “small barrier” for her within the larger scope of the CSP partnership. Ms. Cruz participated in weekly CSP planning meetings, in which the researchers often discussed items related to the research side of the project (e.g., data collection, conference presentations, manuscript drafts). Ms. Cruz noted that the research world was all new to her, that it was “much different than what I was used to.” She described how she felt during episodes of research talk in the weekly planning meetings as,

> So I feel like I'm constantly learning, but I also felt like, because I'm constantly learning, because I don't feel like an expert, sometimes the value of collaboration, my value within the collaboration, I didn't feel like ... there was only so much I could add, in areas that I felt comfortable adding.

Ms. Cruz reflected that she was quieter during the CSP weekly planning meetings than she would normally be at other meetings in her professional life, but that “I definitely lent my support when I felt like I could give it and didn't if I felt like it was better taken by someone else; and I felt like that was okay.” From Ms. Cruz’s interview comments, it appeared that episodes of researcher discourse during the weekly meetings were often not accessible to her, leaving her unable to contribute as much to these discussion as with others in her professional life.

However, in practice, this boundary was actually more permeable than she may have realized. Ms. Cruz played a critical role in supporting many CSP research activities, though she may not have recognized the value of this work as contributing to the CSP’s research initiative. Rather, she may have categorized these work tasks as part of her project management or instructional coaching role. However, there was significant overlap between project management, coaching, and research practices during unit enactment. Ms. Cruz's ability to keep the lines of communication open across institutions, to articulate work processes of the teachers, to help with scheduling data collection activities at the school, as well as her active in-class support of Ms. Ly during the enactment of the biology unit were all contributions to the CSP research endeavor. Ms. Cruz's support of CSP research activities helped to span the boundaries between the university and the school, and between researchers, teachers, and their students. Indeed, in Year Three Ms. Cruz identified herself as "a liaison" between STEM Academy and the University researchers. She described this role as "making sure that the needs at the school are being met, needs at the CISP are being met and making sure that nothing gets lost in translation." Ms. Cruz also became a co-author on a manuscript, an intentional move on the part of the research team to bring her more into the research work, provide a professional learning opportunity, and acknowledge her valuable member checking contributions. Ms. Cruz's boundary spanning role was critical in supporting CSP researchers in carrying out their research tasks.

Ms. Cruz also resourced Ms. Ly during co-planning and debriefing sessions with instructional tools, such as providing her with curricula for facilitating a Socratic Seminar and teaching her how to use the online program, PollEverywhere. Ms. Cruz also tried to mentor Ms. Ly in professional work practices. For example, Ms. Cruz noted that she tried to teach Ms. Ly not to overwork herself, pressing her to "work smarter, not harder," to develop more efficient grading practices, and encouraging her to go home on days when she Ms. Ly still at school at 6:00 pm. Passing along craft knowledge was Ms. Cruz's way of supporting Ms. Ly's professional practice.

During the enactment of the biology unit, Ms. Cruz, Ms. Ly, and I developed a practice of regular debrief sessions held after school. It was Ms. Cruz's idea to create a spreadsheet as a data collection tool for these debrief sessions. Together, Ms. Cruz and I co-constructed a set of questions that we would use to guide each of these debriefs with Ms. Ly. The use of the debrief spreadsheet became a boundary practice, a shared routine that helped coordinate research, instruction, and project planning activities. Ms. Cruz or I used the spreadsheet to record notes during each debrief session, a practice Ms. Ly took up on day's in which neither Ms. Cruz or I were available to meet with her; on those days, Ms. Ly responded to the questions in the spreadsheet on her own. This spreadsheet took on dual functions: guiding instructional debrief and co-planning activities as well as serving as an important tool for data collection.

Ms. Cruz had originally planned on focusing these debrief sessions on "big picture reflection". Instead, she spent a significant amount of that time dedicated to co-planning with Ms. Ly. While detailed co-planning is a standard approach for design-based research enactment work, Ms. Cruz had personally prioritized deep reflection as the goal for these sessions. Reflection, however, became sidelined by Ms. Ly's pressing need to plan out instruction and feel prepared for the following day. For example, Ms. Ly asked for regular support in predicting how long classroom activities would take in practice. Ms. Cruz realized that with Ms. Ly being a second-year teacher who was teaching biology for the first time, Ms. Cruz needed to be responsive to these needs, "supporting her where she needed." However, Ms. Cruz was regretful that she was not able to find the time for reflection in the ways she had originally envisioned. She noted, "reflecting is so important, and that was a piece, I think, we didn't have time for. Yeah, so it was hard." However, research activities did provide Ms. Ly with other opportunities to engage in deeper reflection during researcher interviews, illustrating how core members of the

CSP engaged in the articulation process of interactional alignment, in which they were able to align their actions to carry out critical project tasks. In addition to the co-planning, co-teaching, and debriefing practice, Ms. Cruz also supported the enactment of the biology unit by organizing a field trip, inviting scientists to be authentic audience members for the final presentations, and other supporting activities. These are examples of how Ms. Cruz approached her work within the CSP partnership, which she articulated as, "if you see a need and you can fill it, fill it."

How could researchers have better brought Ms. Cruz into the work and made the research activities feel more available to her? Or would this have been just one more role for Ms. Cruz to fill, when she was stretched across many role categories in her attempts at boundary spanning? Within design-RPPs, researchers might question if the role category of researcher should be made more porous and how could that be accomplished. Bang and Voussghi's (2016) concept of role re-mediation suggests that when members of a partnership are able to take on different roles in porous categories of work, there is an opportunity to disrupt normative hierarchies and power inequities in partnership work. These inequities are often seen in university-school partnerships (Carlone & Webb, 2006), in which researchers research while teachers teach; these role categories are not often porous. However, multiple studies of boundary spanning (Engeström, 2008; Ford & Youngs, 2017; Penuel, Coburn, & Gallager, 2013) have shown that people in boundary spanning positions may need to redefine, shift, and assume different roles within a partnership.

The Importance of a Boundary Role within a Design-RPP

In her final interview, I asked Ms. Cruz if she felt a position like hers that includes what she called a liaison role should be included in similar research-practice partnerships. Ms. Cruz indicated that she saw value in a role like hers especially if the project included working with early-career teachers, or teachers who are new to a focal pedagogical approach like PBL, or if the partnership is funded by a grant that is co-managed by more than one organization. Ms. Cruz saw value in her role in supporting novice science teachers and making their challenges visible to the research team in a boots-on-the-ground way. She explained the value in her contact with these early-career teachers, noting:

> Because I felt like I was able to help in the areas where maybe … the challenges wouldn't have been identified if I weren't there. So meaning on [Ms. Ly's] side or the teachers' side. I think also having had experience--of course then again, if you had a teacher who had more experience, we had a situation where we had novice teachers. And so, I guess, in this case, yes. If you have novice teachers, definitely.

Ms. Cruz went on to note that a role like hers may be less important if experienced teachers were key partners, rather than novices. However, if the project was focused on a particular pedagogical approach like STEM Academy and CSP's focus on PBL which was new to some or all of the partner teachers, then having someone positioned in a coaching role in the way she was could be important. She explained,

> And, you know, another interesting thing is, even if you did have an experienced teacher we primarily teach, or we encourage PBL. And so oftentimes when we have like veteran teachers come and they still need support because they're new to like PBL, they may have other tools in their tool belt, but. So again, there, there are some weird dynamics, because we do encourage PBL. And that's not true for every school.

Ms. Cruz's quote captures the idea that it is important to consider the specific needs of a partnership when deciding on what roles may be important, and to allow those roles to evolve over time as necessary. As this case shows, positioning Ms. Cruz as a boundary spanner resulted in many benefits to the project, but it was not without challenges.

For design-RPPs that involve early-career teachers, it becomes particularly important to consider the ways that novices are supported both in engaging in partnership activities and continuing to improve their own classroom practice. If carefully designed, a design-RPP might serve as a professional learning community and advice network for novice teachers; however it also risks taking their time and focus away from their own professional development in service of partnership activities and goals. While having someone positioned in a boundary spanning role can be helpful for articulating collaborative work processes, sharing insider knowledge, and supporting on-the-ground work and research activities, it is important to consider the individual's home institution and how the institution's cultural and political histories align with those of the other members of the partnership. When individuals come together in these kinds of inter-institutional, cross-practice partnerships, they come together from different social worlds and must design new ways of working together across the boundaries of partnership.

Conclusion

This chapter offers a thick description account of an individual who was purposefully positioned as a boundary spanner within a design-RPP. Through a micro-ethnographic case study of Ms. Cruz as a boundary spanner within the CSP, this study sought to understand what roles Ms. Cruz took on in this design-RPP, and who benefited from her participation. This study also sought to understand how Ms. Cruz crossed the boundaries of the respective institutions in the CSP partnership and in what ways she was supported or constrained in this work. Ms. Cruz was able to successfully span some boundaries through her relational approach to her work and toward building productive and collaborative work relationships. These interactional processes (Strauss, 1988) included persuading, educating, and negotiating other people across roles in the partnership and aligning and coordinating their work. As a boundary spanner, Ms. Cruz engaged in explicit articulating work that focused on interactional alignment across institutional, sociocultural, and professional boundaries. Though this chapter shares the ways in which Ms. Cruz's boundary spanning practices were beneficial to the partnership and its members, it also reveals the ways that Ms. Cruz was challenged in this highly complicated work. Through Ms. Cruz's case, we see how boundaries are influenced by institutional histories and shifting contexts, and that because of this, the roles that a boundary spanner assume may change over time.

The Roles that a Boundary Spanner Assumes May Change Over Time

This analysis shows that the complex processes of boundary spanning may include fluidity in roles that shift over time in response to emergent needs. Ms. Cruz was fluid in her ability to take on different roles, depending on what boundaries were evident and which role categories were porous and available to her (Bang & Vossoughi, 2016). During three years of participation in the CSP, Ms. Cruz was observed taking on the roles of teacher, project manager, communication liaison, instructional coach, teacher-advocate, event planner, committee member, learner, curriculum designer, and more as she worked across the interconnected activity systems of district, school, foundation, and university. As Ms. Cruz revealed in her interviews, this fluidity stemmed from her adaptive expertise, relational expertise, and relational agency (Edwards, 2005, 2011, 2012) and her ability to develop collegial work relationships. This study suggests it may be important for researchers to examine the relational, social, and emotional aspects of boundary spanning behind focusing on routines, tools, and objects.

This analysis also suggests that there is a threshold for role fluidity, in which the boundary spanner may be unable to productively balance multiple roles. As seen with this case study, Ms. Cruz moved through so many roles because that is what was demanded of her by the CSP, her district, school, and the foundation. As a science teacher, Ms. Cruz had never taught the same class two years in a row, nor did she ever have an existing curriculum. Her teaching positions asked so much of her, leaving her overwhelmed, stressed, and exhausted. Once she transitioned from her position as science teacher at STEM Academy to the project manager/instructional coach position with Tech Foundation, Ms. Cruz was hopeful that she could take on a leadership role while leaving behind some of the exhausting parts of teaching. However, in this new position, Ms. Cruz in essence held three jobs. She helped to manage the foundation's responsibilities for the CSP partnership, which involved spanning the boundaries of the foundation, district, school, and university. She was an instructional coach to all science and math teachers at the school. She coordinated the school-wide STEM Symposium event and coordinated other opportunities that connected students with STEM professionals. Underneath these demands of her position, there was also the complexities introduced by the continually shifting landscape of the school merger and changes in mandates issued by the school district. Ms. Cruz obviously cared deeply about her work, the school and its teachers and students. However, it seems that too much was asked of her with too little support. Building the plane as we are flying it, as she described Tech Foundation's approach, was not sustainable for her. After two years in the position, Ms. Cruz resigned and departed Tech Foundation.

Coordinators of similar types of design-RPPs might consider the key roles for a boundary spanner and provide some protections to ensure that the individual does not become overwhelmed by assuming too many roles within the partnership. Researchers might consider if there is value in reimagining roles, or in limiting role categories in order not to overextend the individual placed in the boundary spanning position.

Crossing the (Im)permeable Boundaries of Partnership Work

As we saw with Ms. Cruz's experience with the research side of the partnership, however, it may be important to think carefully about which role categories are porous and which are not, and whether focus should be placed on making certain roles more available.

Researchers might consider partnering and research practices that open up the role of researcher and make this work more available to interested partners, such as employing participatory design research methodologies (Bang & Vossoughi, 2016). However, researchers also must acknowledge that role porosity and re-mediations takes opportunity, trust, support, as well as time. Ms. Cruz's professional life was heavily structured with many demands on her time that did not provide the time to engage more deeply in shared learning with the research team or participate more fully in research activities. This analysis shows value in centering researchers' focus on the amount and types of roles available to a boundary spanner.

Positioning and Supporting Boundary Spanning Roles within RPPs

Acknowledging the value of Ms. Cruz's boundary spanning role within the CSP, the question then is how to craft a position like this one in which the individual is better supported in his or her role. Ms. Cruz's case both highlights the benefits of specifically creating these types of roles within RPPs and provides a caution about the care that is needed to carefully bound the responsibilities of this kind of position. As we see through this case study, it is important to consider the types of expertise that someone needs to bring to the position, and the expertise that they can be supported in developing through participation in partnership work. Ms. Cruz communicated through her interviews the benefits of relational approaches to collaboration, in particular in the collegial relationship and collaboration that existed between herself and the researchers. There was undoubtedly benefits to the CSP partnership from Ms. Cruz's communication and liaison roles, and her ability to share insider and institutional knowledge.

This analysis surfaces questions about the goals of a partnership, who should be positioned in a boundary spanning role, and if this should take the place of researchers developing deep relationships with teachers. In particular, if a goal is institutional change making or supporting teachers' changes in practice, researchers may need to engage in relationship building and boundary spanning themselves, rather than relying on someone else to do this work by proxy and through translation. Researchers should consider both the affordances and constraints of having someone in a boundary spanning role that is an insider of the partner organization or someone external who can be more disruptive.

It is critical to recognize the highly complicated nature of cross-practice and inter-institutional boundary spanning work. Researchers who develop these types of partnerships should carefully consider the institutional, sociocultural, and professional structures and practices that need to be in place to support this complex work and the people charged to do it. This critical lens includes examining issues of power, status, and authority between the members of the partner institutions and how these power dynamics might serve to support the person positioned as a boundary spanner, or may at times function as barriers that inhibit their work.

Implications of this Research

Collaborative design within research-practice partnerships offers a model for the design of reform-oriented science curriculum materials. However, the RPP model is rich with affordances and challenges as participants engage in complex inter-professional and cross-practice collaborations across institutions in the partnership. This is challenging work, especially given how in the CSP, personnel and school structures shifted. This chapter investigates a RPP that purposefully included a position with a boundary spanning role. As O'Neill (2016) and Coburn and Penuel (2016) have called for, published studies of design-RPPs should not just report success stories; learning scientists have much to learn from narratives of tensions, misadventures, and failures in this complex joint work. This chapter reveals some of the challenges involved in positioning novice science teachers as key co-designers in design-based research initiatives. It also suggests the need for care to be taken during partnering processes to surface and identify assumptions that may be made about alignment of vision, stances, and approaches and the development of common knowledge among members of a partnership. The case study methodology results in a detailed account of the complexities involved with the articulation of work across the interconnected activity systems of an inter-institutional partnership. Ms. Cruz's case reveals the dynamics, nuances, and complexity involved with positioning an individual within a partnership in a boundary spanning role.

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Chapter 4: **Professional Learning of an Early-Career Science Teacher through Co-Design in a Research-Practice Partnership**

Professional learning for in-service teachers is often thought of in the context of formal professional development experiences that typically occur outside of the classroom and in response to identified problems of practice. However, these traditional approaches to teacher professional development (PD) have been criticized for being superficial, fragmented, and unsuccessful (Ball & Cohen, 1999). These types of PD experiences are also infrequent. Science teachers spent on average less than 35 hours over a three-year period participating in “formally organized, science-focused” PD activities, which works out to about one and a half days a year spent in formal, science-focused professional learning (National Academies of Sciences, Engineering, & Medicine, 2015, p. 80).

Rather, many researchers (e.g., Ball & Cohen, 1999) suggest a practice-based view of teaching, in which teachers learn *in* and *from* practice, in addition to preparing *to* practice. A practice-based view of teaching includes the idea that there are core or high-leverage practices in which teachers need to develop expertise (Grossman, Hammerness, & McDonald, 2009; McDonald, Kazemi, & Kavanagh, 2013; National Academies of Sciences, Engineering, & Medicine, 2015; Grossman & McDonald, 2008 and Franke & Kazemi, 2001 as cited in Russ, Sherin, & Sherin, 2016). Given that the *Framework for K-12 Science and Engineering Education* (National Research Council, 2012) presents a vision that conceptualizes teaching and learning in ways that differ from standard classroom practice, all science teachers will need some level of professional learning to support the development of the knowledge, expertise, beliefs, professional identity, and repertoire of instructional practices needed to enact this vision.

We know that effective professional learning communities (PLCs) can offer a context for teacher learning (eNational Academies of Sciences, Engineering, & Medicine, 2015). Research-practice partnerships (RPPs) may be structured to serve as a type of learning community for the participating teachers in partnership with researchers. In particular, design-focused research-practice partnerships (design-RPPs; Coburn, Penuel, & Geil, 2013) bring together teachers, researchers, and disciplinary experts with the dual goal of co-designing innovative curriculum materials in response to noted problems of practice, while also pursuing a research agenda. A design-RPP has the potential to function as a type of professional learning community where the ultimate focus resides with teacher learning and student achievement, and the curriculum design work functions as the mediating practice (Linn, Shear, Bell, & Slotta, 1999; Shear, Bell, & Linn, 2004). Therefore, teacher involvement in design-RPPs, where teacher learning is centered *in* practice, can be investigated as an alternative, practice-oriented approach to more traditional forms of professional development. However, the literature base is underdeveloped around our understanding of early-career teacher professional learning through co-design and especially within the structures of design-RPPs.

In this study, I investigated how participation in a design-focused research-practice partnership (design-RPP) might serve as an alternative, practice-oriented context for early-career teacher professional learning. This chapter features a qualitative case study of Ms. Ly, a second-year science teacher who was engaged in a design-RPP. My first research question is focused on understanding this teacher's reports of her own experiences, asking: *How did the involvement of an early-career science teacher in co-design, local adaptation, and reflective enactment of curricula benefit and challenge her professional learning, development of various forms of expertise, and professional practice?* My second research question is broader and considers the practicality, benefits, and risks of engaging novice teachers in these kinds of intensive curriculum design and enactment practices through partnership. I question: *Should early-career teachers be asked to take on critical partner roles in design-RPP endeavors?*

Theoretical and Conceptual Framing

I approached this study with a sociocultural perspective (Rogoff, 1997), focusing my inquiry on the interconnected social, physical, cultural, and historical contexts and factors that influence and shape teaching and learning (Russ, Sherin, & Sherin, 2016). Using a framework of social practice theory (Holland & Lave, 2009) and expansive learning (Engeström, 2001), I sought to understand, in the context of a design-RPP, what practice-oriented professional learning pathways (Bell, Tzou, Bricker, & Baines, 2012; McDonald, Kazemi, & Kavanagh, 2013; Penuel, DiGiacomo, Van Horne, & Kirshner, 2016) influenced and supported a teacher's professional learning as she engaged in collaborative curriculum design practices as part of a design-focused research-practice partnership. This view considers how professional learning occurs across time as well as across contexts (McDonald, Kazemi, & Kavanagh, 2013), including learning-to-teach contexts (Thompson, Windschitl, & Braatan, 2013) and teachers' everyday workplaces.

Sociocultural perspectives drive a contemporary interest in practice-based teaching, claiming that teachers need not just knowledge, but a "rich repertoire of teaching practices" to support learning in the specific contexts of their classrooms (Davis & Boerst, 2014). Working from a practice-based view of teaching, Ball and Cohen (1999) offer their ideas of what teachers need to know in order to successfully engage in the work of teaching; these ideas go beyond a purely cognitive view of teacher thinking to a broader view of teacher expertise. In this view, teachers need to: know the subject matter they teach; develop repertoires of practice for engaging students and building classroom culture; have an ambitious view of how children (can) learn; and understand their students' cultural, linguistic, and socioeconomic backgrounds, while also considering the "resource and liability" of their own frame of reference (p. 9). Davis and Boerst (2014) adds to Ball and Cohen's (1999) list that teachers also need to be well versed in understanding the relevant state or national standards and that their disciplinary knowledge should include core disciplinary ideas as well as themes that cut across disciplines. This focus has inspired the (re)design of practice-oriented teacher education programs that aim to graduate well-started teachers (Davis & Boerst, 2014; Hollon, Roth, & Anderson, 1991) who are ready to engage in the complex work of teaching in a reform-oriented school environment.

Practice-Oriented Contexts for Teacher Professional Learning

Teacher learning occurs in a variety of contexts in a teacher's professional trajectory: from pre-serve to in-service settings, and from early-career through veteran experience (that is, for those early-career teachers who remain in the profession). The main pre-service context for learning is the teacher education program, which traditionally includes both coursework and field placement, ideally with mentoring and coaching throughout. With the growing popularity of alternative teacher certificate programs ("alt-cert") in response to teacher staffing shortages, including programs like Teach for America (TfA), learning for pre-service teachers now may occur in other contexts and accelerated formats, including online learning. Secondary science teachers are thirty-five percent more likely to have obtained their certification through an alternative pathway than the average teacher, which may be due to the use of alt-cert programs to meet the demands of science teacher shortages, especially for urban, low-income schools with high percentages of underrepresented minority students (National Academies of Sciences, Engineering, & Medicine, 2015).

For in-service teachers, a sociocultural perspective views teacher learning as occurring every day in many contexts, as it is situated in the classroom and workplace in interactions with students, teaching colleagues, administrative staff, parents, and community members—as well as through the use of tools. For subject-matter teachers, expertise may be developed in ways that are specific to their discipline. Often professional learning for in-service teachers is thought of in the context of formal professional development experiences offered by the school, district, or an external organization. This learning typically occurs outside of the classroom, in response to identified problems of practice, and may span anywhere from brief "one-shot" workshop to longer, sustained approaches.

However, critics of these common approaches to PD worry that in-service teachers are thought of as "needing updating" rather than as serious professionals engaged in learning across topics that continues throughout their careers (Ball & Cohen, 1999, p. 4). Rather, Ball and Cohen (1999), with a practice-based view of teaching, insist that teachers should learn *in* and *from* practice, rather than prepare *to* practice. The authors (Ball & Cohen, 1999) explain that while "teachers can certainly learn subject matter, as well as knowledge of children, learning, and pedagogy in a variety of courses and workshops", the knowledge that is necessary to teach "cannot be learned entirely in advance or outside practice" (p. 12). How would this type of learning occur? They suggest that teacher learning be centered *in* practice within an established learning community (Ball & Cohen, 1999). Learning in/with community is an important component of Ball and Cohen's (1999) vision of professional learning, which they argue should occur in collaboration with teaching colleagues; these researchers also push for a wider conceptualization of a teachers' community of practice, to include university-school partnerships, in order to leverage distributed expertise, expand teachers' social networks, to broaden their visions of teaching and learning.

Core Practices of Instruction

A practice-based view of teaching has been framed to include the idea that there are "central interactional practices" in which teachers need to develop expertise (Russ, Sherin, & Sherin, 2016, p. 404). This idea has been described by different authors as "core practices" (Grossman & McDonald, 2008), "high-leverage practices" (Boerst et al., 2011), and "generative practices" (Franke & Kazemi, 2001) (all as cited in Russ, Sherin, & Sherin, 2016). High-leverage practices are those that "support student work that is fundamental to the discipline, and that they improve learning for *all* students" (National Academies of Sciences, Engineering, & Medicine, 2015, p. 102). Core practices are those that occur in the classroom at high frequency, are research-based and potentially linked to increasing student achievement, and are the kinds of practices that novice teachers can actually learn to master and enact within their teacher education programs (Grossman, Hammerness, & McDonald, 2009; McDonald, Kazemi, & Kavanagh, 2013). These types of core practices are the focus of practice-oriented teacher education programs, as they are a way to support pre-service teachers in being prepared for the complex work of teaching (National Academies of Sciences, Engineering, & Medicine, 2015; cf. Philip et al., 2018).

Examples of practices that have been identified as "core" include orchestrating a classroom discussion (Grossman, Hammerness, & McDonald, 2009) or setting up and managing group work (Davis & Boerst, 2014), which require specialized and everyday teacher knowledge (Russ, Sherin, & Sherin, 2016). For a beginning science teacher, a core practice may include selecting big ideas and anchoring phenomena (National Academies of Sciences, Engineering, &

Medicine, 2015; Thompson, Windschitl, & Braaten, 2013), eliciting students' ideas and adapting instruction (Thompson, Windschitl, & Braaten, 2013; Windschitl & Calabrese Barton, 2016), identifying students' everyday science understandings (Russ, Sherin, & Sherin, 2016), or pressing students for explanations of scientific phenomenon (Thompson, Windschitl, & Braaten, 2013). It is important to note that while a practice may be labelled as a core practice, it does not mean that its implementation in the classroom will be uniform across teachers in all contexts.

Core practices, a type of *specialized* professional skill, are often the focus of teacher education, however, Russ, Sherin, and Sherin (2016) make a case for identifying, considering, and refining the *everyday* knowledge that is also critical to this work. This idea traces back to the late 1980s and 1990s across multiple scholars (i.e., Minstrell, diSessa, Linn, Warren, Rosebery, Zimmerman, and Bell). Examples of everyday knowledge include expertise in practices such as holding a conversation, making inferences, and time management, as well as a possessing specific subject-matter knowledge, and particularly relevant for science teachers, "commonsense understandings of the natural world" (Russ, Sherin, & Sherin, 2016).

Supports for Early-Career Teachers

Teacher turnover and attrition rates are especially high for science and math teachers (Carver-Thomas & Darling-Hammond, 2017; National Academies of Sciences, Engineering, & Medicine, 2015). Carver-Thomas and Darling-Hammond (2017) note that data from a nationally representative survey of public school teachers revealed that "mathematics and science teacher turnover rates are nearly 70% greater in Title I schools than in non-Title I schools, and turnover rates for alternatively certified teachers are more than 80% higher" (p. v). Moreover, in schools that serve largely students of color, turnover rates are ninety percent higher for math and science teachers and one hundred and fifty percent higher for alternatively certified teachers than schools serving largely White students (Carver-Thomas & Darling-Hammond, 2017, p. v). The survey data also revealed higher turnover rates for young teachers under 30 years old and those who worked at small schools (Carver-Thomas & Darling-Hammond, 2017, p. vi). Teacher attrition is a significant problem for the field of education, with many teachers who choose to leave the profession citing the reasons for their dissatisfaction as including a lack of professional support from administrators, the isolating effects of traditional professional culture of their schools, test-based accountability pressures, working conditions, lack of advancement opportunities, and personal and financial reasons (Baker-Doyle, 2011; Carver-Thomas & Darling-Hammond, 2017). Predictors for teacher turnover and attrition include school characteristics, teacher characteristics (especially their preparation pathway), subject area (with math and science teachers experiencing higher turnover rates), and workplace conditions (Carver-Thomas & Darling-Hammond, 2017).

In their first few years of teaching, early-career teachers face struggles with pedagogy and content, as well as with building collegial relationships with colleagues, navigating school politics, and developing support networks (Baker-Doyle, 2011). These teachers may be supported through participation in teacher induction programs, school-based professional learning communities, or by developing supportive social networks.

Teacher induction programs. Designing teacher education programs centered on core practices with the intent to develop well-started beginners is one approach to solving the problem of teacher attrition (Davis & Boerst, 2014; Hollon, Roth, & Anderson, 1991). However, the role of professional culture and support for newly in-service teachers also must be examined. Teacher induction programs attempt to fulfill this role by providing coaching, mentoring, networking, and other supports to newly in-service teachers, many of whom feel unprepared to teach in the real context of schools (Davis & Boerst, 2014; National Academies of Sciences, Engineering, & Medicine, 2015). Within induction programs, instructional coaching often focuses on effective teaching practices and may be offered in groups or one-on-one, though this individual level of attention remains rare for science teachers, with only seventeen percent of elementary and middle school teachers and twenty-two percent of high school science teachers receiving one-on-one coaching (National Academies of Sciences, Engineering, & Medicine, 2015). While mentoring and instructional coaching are known to be helpful for early-career teachers and are a recommended best practice (Carver-Thomas & Darling-Hammond, 2017), these practices are not widely available to most early-career teachers.

Professional Learning Communities. Teacher participation in communities of practice, including professional learning communities (PLCs), can offer support for professional learning as new teachers build their repertoire of instructional practices. Effective professional learning communities can positively impact science and math teachers' professional practice, including their conceptual understandings, attention to student thinking, confidence in teaching science, and self-efficacy (e.g., Vescio et al., 2008; Hamos et al., 2009; Richmond & Manokore, 2011; Lakshmanan et al., 2011; all as cited in National Academies of Sciences, Engineering, & Medicine, 2015). Fulton and colleagues (2010 as cited in National Academies of Sciences, Engineering, & Medicine, 2015) reported on other studies that demonstrated that sustained participation in discipline-specific PLCs (within STEM subjects) increased the teachers' deliberations about their students' scientific and mathematical thinking.

The formation of *collegial*, not just friendly and professionally superficial congenial, relationships is a key component of professional learning communities (Barth, 2006). Teachers who have collegial relationships engage in a substantive discourse of practice (Ball & Cohen, 1999; Barth, 2006; Horn & Little, 2010) or "deep talk" (Himley, 1991 as cited in Nelson, Deuel, Slavit, & Kennedy, 2010), share the craft knowledge they have acquired over years of practice, make time to observe each other's teaching practice, and have a vested interest in each other's success (Barth, 2006). Collegial relationships allow for productive forms of collaboration to occur within a learning community.

Social networks. School-based professional learning communities are an example of a type of network that may offer support in additional to professional learning opportunities. New teachers build social networks that may include their professional colleagues at their school (Intentional Professional Networks), and "non-professionals" such as students, parents, classroom volunteers, and community members (Diverse Professional Allies) (Baker-Doyle, 2011). For new teachers, an Intentional Professional Network helps them "navigate the norms of their school, establish their status and professional identity, solve everyday problems, and feel more confident about their work within the school building" (Baker-Doyle, 2011, p. 22). Diverse Professional Allies may provide "boundary-crossing ties" with student and parent communities, and may help a new teacher develop innovations, challenge norms, and leverage community resources and support (Baker-Doyle, 2011). Advice networks, a type of social network, provide teachers with a source of professional advice and mentorship (Baker-Doyle, 2011). By extending their social network to outside of the school building, such as through a university-school partnership, teachers may benefit from new information and expertise (National Academies of Sciences, Engineering, & Medicine, 2015).

Design-focused RPPs as Contexts for Teacher Professional Learning

Undeniably, teaching is complex work that involves the interweaving of diverse forms of knowledge and skills, including deep disciplinary knowledge, with the ability to leverage, adapt, and design tools. The work of teaching includes developing particular beliefs and types of professional identities, and building expertise with instructional practices—both pedagogical and logistical. Teachers continue to learn and adapt as problems of practice arise and present learning opportunities. The work of teaching requires the ability to build interpersonal relationships and social networks, and to work within activity systems rooted in cultural, social, political, and historical contexts, ranging from the science classroom and school building to the school district and community. Teaching is physical, emotional, creative, intellectual, and oftentimes, isolating work. Design-focused research-practice partnerships offer an alternative to traditional forms of teacher professional development in which teachers are engaged in professional learning in practice. In these partnerships, teachers build collaborative relationships with researchers, disciplinary experts, and other collaborators and engage in the design and enactment of innovative curriculum materials.

There is much that the research community has yet to investigate regarding science teachers' learning and participation in design-RPPs when the collaborators are early-career science teachers. In design-RPPs, teachers may take on important roles, such as designer of curriculum materials, teacher for the enactment of these new curriculum materials, and research partners. On the one hand, early-career teachers may be eager to join the work of a design-RPP. As the literature on teacher induction programs and social networks has shown, early-career teachers may benefit from the support of coaching, mentoring, and an expanded professional social network that includes building relationships outside of their schools. Early-career teachers possess prior experiences and expertise that may be relevant and leveraged by partnership work. They may also bring curricular and instructional flexibility, as they are not yet rooted firmly in their practice. If their school does not require the use of a common curriculum, they may need to build their own course curriculum and be hungry for curriculum resources to help them get started. A design-RPP may serve some of these functions for the teacher, and may benefit from the teachers' flexibility, interest, prior expertise and experiences, and collaboration.

On the other hand, a first or second year teacher does not have much experience yet with using and adapting curriculum materials, let alone designing them. The way that teachers interact with and use curriculum materials changes over the trajectory of their career. Grossman and her colleagues (2000 as cited in Russ, Sherin, & Sherin, 2016) explain that a pre-service or newly in-service teacher is at the stage of searching for materials for their courses, while first year teachers work closely from a particular set of curriculum resources with some fidelity, not engaging in much adapting, changing, or critiquing until their second year, or when they have used the materials two or three times. Early-career teachers are still developing their instructional practices, along with their beliefs and professional identities. New teachers who participate in a design-RPP are asked to design curriculum while at the same time they are developing their own classroom practices. These complex factors led me to question both the benefits and challenges of engaging early-career teachers in design-RPPs, from the perspective of both the teacher and the partnership.

Overview of the Case Study

This case study within a larger design-based research study (The DBR Collective, 2003) employed qualitative methods (Merriam & Tisdell, 2016) to study the Computational Science Project (CSP), a four year project funded by the National Science Foundation. The CSP was structured as a design-focused research-practice partnership that brought together science teachers, learning scientist researchers, disciplinary experts, and community partners. The CSP partners included the university, Tech Foundation (a non-profit organization focused on STEM education), a school district, and STEM Academy (a public school within the partner district that was co-managed by Tech Foundation) that later due to a school merger, became Cascade STEM School. (Refer to Chapter One for more details). The CSP's major goals were to employ collaborative design strategies to develop computationally-rich (Weintrop et al., 2016) secondary science curriculum units grounded by a lens of equity and social justice, while pursuing a research agenda related to teacher, student, and scientist learning. (See Chapter 1 for details on the CSP).

Through a cultural learning pathways perspective (Bell, Tzou, Bricker, & Baines, 2012; McDonald, Kazemi, & Kavanagh, 2013; Penuel, DiGiacomo, Van Horne, & Kirshner, 2016), this case study describes the experiences of an early-career, high school science teacher, Ms. Ly, in order to understand her professional learning. The case focuses on Ms. Ly's participation as a key partner in a curriculum design initiative during the third year of the CSP partnership. At the time of the study, Ms. Ly was in her twenties and in her second year of teaching science and math courses at a public secondary school.

Ms. Ly was Vietnamese American, having grown up in Vietnam. She immigrated with her family to a suburban city in the Pacific Northwest of the United States when she was fourteen years old. She arrived in the U.S. just two weeks before the start of high school. While growing up in Vietnam, she took classes in English language, however they were mostly focused on writing and grammatical structure, with less of an emphasis on speaking and listening comprehension. When she began high school in the U.S., she started classes "with like low English, like close to zero."

The high school Ms. Ly attended had an emphasis on health sciences education. As a high school student, Ms. Ly did not have a specific career aspiration, but "I pretty much tell everyone that in high school when I was like at my students' age right now, I didn't know what I wanted to become but I knew at least that teaching was the last thing on my list." As a high school junior, she was accepted into a two-week summer biomedical-focused education program hosted by a local infectious disease research institute. At the time she felt, "Wow, this is really cool and you look so smart doing it." The director of the program became a scientist mentor and a champion for Ms. Ly, helping her through the college application process and doling out career advice. Ms. Ly credits the summer program and the director's mentorship as the inspiration for her studying science.

Ms. Ly attended a large, urban research university in the Pacific Northwest where she began to think about a pre-med track. During her university studies, she worked as a lab assistant for the same infectious disease research institute washing glassware and stocking equipment, and then transitioned to a lab intern in which she worked for two labs—one focused on influenza research and the other on HIV studies. Over the summer, she worked full-time as an intern, then continued into the school year part-time. Ms. Ly graduated with a Bachelor's of Science in biochemistry and biophysiology. She brought this disciplinary content knowledge and prior experiences to her work as a teacher.

Ms. Ly could be described as a reluctant teacher with no commitment to the teaching field, as teaching was not something she aspired to for a career. She stayed firm in her decision that she did not want to be a teacher through high school and almost all four years of college, stating "I did not want to become a teacher at all." However as a senior, recruiters from Teach for America (TfA) made a presentation during one of her classes about the high need for female teachers of color who could teach science. Teach for America recruits college graduates to obtain their teaching credentials through a fast-tracked certification program while teaching in high-needs public schools. TfA corps members make a two year commitment to the program. After attending a meeting with a recruiter, Ms. Ly was left reflecting on her own experiences entering high school with limited English experience and the impacts that her own teachers had on her, noting “I wouldn’t be the person that I am today without them.” Ms. Ly expressed her emerging drive to teach as wanting to play the role in her students’ lives that her own teachers played in her life. “I thought I wanted to become that person to someone else, to another—at least some students that were in the same situation as I was in back then.” She noted that TfA was “good at recruitment.”

Ms. Ly’s TfA training consisted of a five week summer training. She described the first week as involving training on a variety of topics, including classroom management, student engagement strategies, and content delivery, with a strong emphasis on equity in education. For the following four weeks, she transitioned to spending each morning delivering a practice lesson during one teaching period, and then attending more trainings in the afternoon. She was part of the secondary science cohort and did not receive any professional development in math instruction during her TfA summer training (which becomes salient when she is later assigned to teach math courses). After the five week program, Ms. Ly returned to the same university as she had attended for her undergraduate studies, where TfA enrolled her in a year-long accelerated, alternative teacher certification program. TfA placed her as a teacher-of-record at STEM Academy—a STEM-focused public school that served students in grades six through twelve—while attending courses at the university once per week. At the end of that school year, she earned her teacher certification with an endorsement in secondary biology. In comparison, most teacher candidates through traditional certification programs receive eight to twelve weeks of clinical practice as student-teachers (Humphrey & Wechsler, 2008). As a TfA corps member, Ms. Ly did not have this kind of extended, mentored student teaching experience. She later would reflect in an interview, “I think I’m under-prepared to stand in front of students.” Also, because she did not have a student-teaching experience at STEM Academy, she did not have the opportunity to be encultured into the school culture and pedagogies before launching her first year as a teacher.

STEM Academy was a small, STEM-focused, public neighborhood school serving students in grades six through twelve in a suburban area of the Pacific Northwest. The school prioritized project-based learning (PBL) as a pedagogical approach across disciplines. The school was co-managed by the school district and the non-profit Tech Foundation. The school was known for its success in serving a culturally, linguistically, and financially diverse student population, in which one hundred percent of students who graduated on-time were accepted into college. The school’s teaching staff was comprised of many young and novice teachers. During her first year of teaching, Ms. Ly’s science teaching colleagues and mentors were first and second year teachers. As a small school, science teachers were regularly asked to also teach math courses outside of their certification.

Though her background and endorsement was in biology, STEM Academy’s principal asked Ms. Ly to teach a tenth grade chemistry course and a math course as a first year teacher. In that role, she shared a classroom with and was mentored by second year science teacher Ms. Eider and also received mentoring from Ms. Cruz, a former STEM Academy science teacher who that year had transitioned to a project manager/instructional coach position with Tech Foundation (See Chapter Three for a case study centered on Ms. Cruz). Ms. Ly also collaborated with Mr. Sherman, another first year science teacher. In the first few months of her first year of teaching, Ms. Ly enacted the CSP’s chemistry unit, following one day behind Ms. Eider and Mr.

Sherman. This arrangement allowed her to observe one class period of Ms. Eider's delivery of the chemistry curriculum, and then enact the lesson with her own students the following day. Data collection activities focused on Ms. Eider's classroom during the unit enactment. Ms. Ly and Mr. Sherman's enactment of the CSP chemistry unit was not studied for research purposes out of respect of it being their first year as teachers.

Toward the end of her first year, Ms. Ly was asked by her principal to take on a key teacher-designer role with the CSP. It should be noted that working with early-career teachers was not by design; rather, STEM Academy's science faculty were mostly first and second year teachers. In this capacity, Ms. Ly engaged in co-design activities over the summer and the following academic year specific to the design of two computationally-rich biology curriculum units, one focused on evolution and Sea Star Wasting Disease and the other focused on infectious diseases and influenza. The following academic year, STEM Academy at the request of the district merged with Cascade School, a middle school in the same district. Ms. Ly and many other STEM Academy teachers transitioned to the new, merged Cascade STEM School at the site of the former Cascade School. For STEM Academy teachers, the merger changed their school's physical location, its culture, a large increase in the size of its student body as it more than doubled, and changes to its faculty and administration team. The school merger created many cultural and structural challenges, as detailed in Chapter One and Chapter Three.

At Cascade STEM School, Ms. Ly—now in her second year of teaching—was asked to teach ninth grade biology, as well as a ninth grade advanced algebra math course, outside of her certification. Ms. Ly enacted the two CSP biology units in the fall and spring. This was her first time teaching a biology course or working with ninth grade students. She was now at a new school, with new administrators and colleagues, with many new students with which she had yet to develop a relationship. This case study focuses on her enactment of the biology evolution unit in the fall through early-winter of her second year of teaching. The biology evolution unit (described in more detail in Chapter Five) was a curriculum focused on the topics of evolution, climate change, and computational thinking. The anchoring phenomenon was the West Coast outbreak of Sea Star Wasting Disease that began unfolding in 2013. The unit incorporated a project-based approach to involving students in computational thinking practices and using computational tools. Students worked in teams to collect, analyze, and represent data from publically-available professional datasets related to different aspects of the disease outbreak and its impacts on sea star populations across different geographic locations. Each team then produced an infographic that featured line graphs, geospatial models, and causal loop diagrams. Computational tools included Google Sheets and Google Maps. (See *Appendix B* and *Appendix G*).

This case study unfolds as Ms. Ly participated in co-design and planning activities at the end of the summer and then enacted the biology evolution unit from November 2017 through January 2018. She also enacted the biology infectious disease unit later that spring. At the end of that year, which represented the end of her commitment to TfA, Ms. Ly resigned from her position and left the teaching profession in order to enroll in a graduate program to prepare her for a career in health care. Therefore she is not a novice teacher in the traditional sense who was just beginning a long teaching career where she would continue to refine her practice; rather she was nearing the end of a two year teaching experience.

In the fall of 2017, standing in the front of her new classroom at Cascade STEM School, Ms. Ly was a petite, slight-framed woman; most of her ninth grade students were taller than her. She wore dark-framed glasses, with her straight black hair worn down or pulled back into a low ponytail. Ms. Ly dressed professionally in classic slacks, skirts, and cardigan sweaters, with flats or low-heeled boots. Her science classroom was located at the end of a hallway. It was set up with tall lab tables and stools in the center, with built-in lab stations, sinks, and cabinets along the walls. Cardboard boxes were stacked against some of the lab stations, evidence of the recent move to the new school. Ms. Ly began each class period with a slide projected on the large screen at the front of the room, instructing students of their warm-up activity as she welcomed students with a warm smile.

Methods

This chapter presents a qualitative case study (Stake, 2005; Yin, 2014) of an early-career high school science teacher's professional learning pathways as she engaged in co-designing, adapting, and teaching computationally-rich biology curricula. This case occurred within the larger CSP project, a design-based research study (The Design-Based Research Collective, 2003). Data was collected using ethnographic field methods (Emerson, Fretz, & Shaw, 2011) across all four years of the CSP, however, this case study focused on Year Three, 2017-2018. These data provide insight into Ms. Ly's own story, including her background and perceptions of her experiences, set against the larger context of the CSP. Single case study is a useful methodology (Stake, 2005; Yin, 2014) for examining the experiences of a single individual within a larger activity system.

Ms. Ly was chosen for this study because she was a key partner in the CSP; in Year Three of the partnership, she was the teacher involved in the design and enactment of the biology units. During this time, Ms. Ly also received intensive support by Ms. Cruz and researchers in co-planning, co-teaching, and debriefing during her enactment of two CSP biology curriculum units. These practices were developed based on the researchers' experiences working with two other early-career teachers (Ms. Eider and Mr. Sherman) during the design of a chemistry unit in Years One and Two of the CSP. Ms. Ly's case provided an opportunity to investigate the benefits and challenges of these additional supports.

The first research question for this study is focused on Ms. Ly's own account of her experiences and professional learning through her participation in the CSP, therefore key data were the three semistructured interviews that I conducted with Ms. Ly. These interviews totaled approximately four and a half hours of conversations. They took place at the following points in Year Three of the CSP: November 2017 at the end of the week in which Ms. Ly launched the biology evolution enactment with two sections of ninth grade students; March 2018, approximately two months after the conclusion of the biology unit enactment; and June 2018 during the last week of the school year. An interview protocol was developed prior to each interview. Ongoing analysis of data throughout the lifespan of the CSP informed the topics that were included in each interview protocol. Examples of constructs included in the interview protocols included professional background, previous curriculum design experience, definitions of collaboration, perception of different roles on the design team, reflections on the design process and unit implementation, areas of growth and learning, sources of support, and perceived impact of participating in the project. Data from interviews included field notes, analytical memos, video recordings, and transcripts.

Supporting data from the CSP data corpus included audio/video recordings, field notes, and analytical memos from twenty-two classroom observations of the biology evolution unit enactment, fifteen post-instruction debrief sessions with Ms. Ly, and thirty-one entries in an instructional debrief journal recorded collaboratively by Ms. Ly, Ms. Cruz, and myself, as well as several co-design meetings. In order to answer the second research question, I also analyzed two interviews with one other early-career science teacher involved in the CSP, Mr. Sherman, who participated in the CSP for two years as a student-teacher and during a portion of his first year of teaching.

Throughout all four years of the CSP, researchers engaged in ongoing analysis that included the development of analytical memos after data collection activities. These memos were shared among the research team and often influenced changes to design processes. As part of this practice, after meeting with Ms. Ly for each of her interviews, I wrote an analytical memo and shared it with the rest of the research team, providing an opportunity for us to discuss themes as they emerged. During data analysis for this chapter, those analytical memos were revisited during open coding (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016; Strauss & Corbin, 1990), along with field notes and transcripts of Ms. Ly's interviews. Coding consisted of both *in vivo* codes as well as *a priori* concepts from my conceptual framework that focused on understanding Ms. Ly's personal and professional background including different contexts for professional learning, her perceptions of herself as a teacher, professional goals, areas of expertise and learning, her sources of support, and her feelings about participating in the CSP. When analyzing Mr. Sherman's interview data, I was specifically focused on his perceptions of his experience as a teacher within the CSP partnership. Data was revisited when writing the case study to develop a thick description (Geertz, 1973 as described by Merriam & Tisdell, 2016).

Findings and Analysis

In this section I share findings related to Ms. Ly's case study, and how she reported that her involvement in the CSP partnership benefited and challenged her professional learning, development of various forms of expertise, and professional practice. My analyses showed that Ms. Ly developed various forms of expertise through her participation in co-design, local adaptation, and enactment of curriculum within the CSP design-RPP. She also experienced some shifts in her teaching practice. However, though she reported the experience as beneficial to her, Ms. Ly also encountered challenges and barriers to her professional learning through this experience.

In this section, I first share the personal and professional resources that Ms. Ly brought to her teaching position. I then describe how she was engaged in professional learning around developing core practices of instruction that while tangential to the goals of the CSP, were deliberately supported through routines developed through the CSP partnership. I highlight several areas of expertise that Ms. Ly developed through her participation in the CSP, including expertise with project-based learning that used scientific phenomenon to anchor instruction, expertise with computationally-rich science instruction, and the development of repertoires for collaboration through the CSP co-design model. As part of this focus on her professional learning through partnership, I also highlight a vignette in which Ms. Ly experienced a shift in her instructional stance during her enactment of a CSP curriculum unit. Finally, I share findings related to Ms. Ly's ability to develop an advice network that provided professional and emotional support, and conclude by sharing how the emotional burden of teaching influenced Ms. Ly's decisions to leave the teaching profession and instead return to her original plan to attend graduate school.

Personal and Professional Resources

Ms. Ly brought many personal and professional resources to her position as a teacher, including her training in biology and infectious diseases. She also seemed flexible and open to coaching, often trying out a new instructional strategy or tool the day after discussing it with Ms. Cruz or researchers. As a female woman of color and an immigrant, she was motivated to teach so that she could support her students in the way she had been cared for by her own teachers. She was also motivated by the school's social justice and equity orientation. Ms. Ly saw herself a relational teacher with an ethic of care for her students. Often, in conversations about curriculum design or local adaptations, she spoke about how to best engage her students and how to connect with their interests. She also cared about how students felt in her class and the relationships she developed with them. Note Ms. Ly's focus on relationships and her use of the words "feel" and "comfortable" in this interview excerpt, when she was asked to describe herself as a teacher.

> As a teacher, I <u>feel</u> like I focus a lot on the <u>relationships</u> side of students. So I want to make sure that students <u>feel</u> <u>comfortable</u> with me, <u>feel</u> that they…can be <u>comfortable</u> coming to me for anything and not just like the content. Because I <u>feel</u> like teachers is more than just a person who delivers the information, and for a lot of the time I feel like I would place more significance on how students <u>feel</u> being in my class than they being--not over--I don't want to say that it's like it's more important for students to <u>feel</u> <u>comfortable</u> and not so much of their learning…So that kind of guide my practice in how I approach them in the class that is more important that they have the skill coming out and that they <u>feel</u> like their opinion and their contribution is valued in the class more so than specifically, "You need to know the mitochondria is the powerhouse of the cell." [Emphasis added].

In Ms. Ly's vision of herself as a teacher, how students felt in her class room was as important as the content knowledge that they gained. She felt that a teacher should be "more than just a person who delivers the information." However, Ms. Ly also needed to help her students develop biology content knowledge and scientific practices.

Developing Core Practices of Instruction

As a novice teacher, Ms. Ly was seen working on developing core practices of instruction (Grossman, Hammerness, & McDonald, 1999; National Academies of Sciences, Engineering, & Medicine, 2015; Russ, Sherin, & Sherin, 2016). For example, when asked in an interview what she was working on in her practice, she described her need to develop classroom management techniques, particularly for discipline and keeping students accountable to expectations, as well as learning how to design effective assessments of student learning and develop efficient grading practices. She was continuing to work on her comfort with public speaking, and also learning to be gentler with herself, realizing that she cannot blame herself for everything that happens in her students' lives. In addition, Ms. Ly recounted that her TfA training did not prepare her for many of the non-teaching aspects of her job, such as how to deal with conflict, how to interact with parents, and how to communicate with administrators and seek out support from colleagues.

Ms. Cruz, who acted as Ms. Ly's instructional coach as well as her co-planner and co-teacher during the CSP biology unit enactment, described Ms. Ly in an interview as being a novice in her craft, operationalizing this term not just related to her years of experience as a teacher, but based on the level of support she needed to be successful in the classroom. Ms. Cruz described Ms. Ly as a novice teacher who was "really trying to figure out what works" as far as strategies to deliver content, increase student engagement, and manage behavior and time in the classroom. This captures the idea that Ms. Ly was in the process of developing critical core practices. She also needed specific support in facilitating student projects through the school's PBL model, including the core practice of setting up and managing group work (Davis & Boerst, 2014). Ms. Cruz worried that Ms. Ly dedicated too much time to instructional planning and grading, knowing that she stayed late after school and worked many hours at home preparing for instruction.

In one of her two biology class periods during the CSP unit enactment, Ms. Ly often had up to three or four additional adults in the room: Ms. Cruz as a co-teacher, an instructional aide for a special education student, an additional instructional aide who was assigned to the class at Ms. Cruz's request, and at times, help from the researchers who were there making observations.

While Ms. Ly acknowledged that this was a “luxury” to have so many adults in the room, it also is testament to the fact that she needed a high level of support.

Likewise, she met with Ms. Cruz for daily CSP debrief sessions during her planning period, which I often attended as well. However, rather than using these debriefs as a space for reflection on the enactment to inform revisions that would serve the broader CSP goals as originally intended, Ms. Ly needed to focus the time on planning out the next day’s instruction. In an interview, she explained how she and Ms. Cruz shifted the focus of these debrief sessions over time, so that more time could be devoted to co-planning. In addition, Ms. Ly often sought out Ms. Cruz during lunch, after school, or even communicated with her over weekends in order to plan instruction. Much of Ms. Cruz’s coaching was focused on helping Ms. Ly develop core practices of instruction, rather than specifically helping her develop confidence in teaching computational thinking practices or supporting her understanding of the CSP’s vision. Instead, Ms. Cruz for example encouraged her to use a timer to keep track of the length of activities, provided her with a Socratic Seminar protocol to help her orchestrate classroom discussions (Grossman, Hammerness, & McDonald, 2009), and introduced her to games to teach students important vocabulary terms.

These core practices, while important to Ms. Ly’s own professional learning and classroom practice, were tangential to the CSP’s goals. However, the development and refinement of core practices of instruction is exactly what novice teachers should be doing. Given that many novice teachers feel unprepared to teach upon attaining their own classroom (Davis & Boerst, 2014; National Academies of Sciences, Engineering, & Medicine, 2015), it is important to consider how formal or informal induction programs that include mentorship and instructional coaching (National Academies of Sciences, Engineering, & Medicine, 2015), like what Ms. Cruz provided Ms. Ly through the structure of the CSP partnership, may support novice teachers in developing needed core instructional practices. Supporting early-career teachers through mentoring and coaching relationships should include "authentic" collegiality and collaborative interactions that encourage teacher agency over curriculum, and allow for teachers to develop leadership roles (Baker-Doyle, 2011). Social networks, professional communities of practice, and university-school partnerships like the CSP partnership may be approaches to supporting early-career teachers in these ways.

Development of Expertise through Professional Learning

Ms. Ly did not feel that she developed expertise or increased her confidence in curriculum design, aligning instruction to the Next Generation Science Standards, or developing three-dimensional assessments through her CSP experience because she felt that the CSP co-design model did not deeply engage her in these processes. Given that STEM Academy did not use fixed curricula, she had previously been engaged in curriculum design and NGSS-alignment for her own course curriculum. Ms. Ly viewed the CSP biology curriculum materials as being well drafted and noted that the NGSS-alignments had already been provided for her. Instead, her focus was more on local adaptation (Barab & Luehmann, 2003) as she made adaptations to the curriculum-as-written to fit the needs of her school, classroom, and students. She also engaged in micro-adaptations between her two class periods of biology, due to differences in class size, students' differentiation needs, and behavioral issues among the two class periods.

Ms. Ly was able to identify the specific forms of expertise that she believed teachers needed to have or to develop in order to participate in similar co-design endeavors as the CSP. She felt that teachers needed to have curriculum design expertise, disciplinary content knowledge, teaching experience for "more tools in their pocket", and professional work experiences outside of the field of teaching to provide them with greater perspective. In her interviews, Ms. Ly shared her thoughts about the expertise that she personally developed directly as a result of her participation CSP activities. These areas of developing expertise included comfort with phenomenon-driven science instruction, confidence in teaching computational practices and using computational tools in the classroom, and developing repertoires of practice for collaboration with university researchers.

Expertise with PBL and phenomenon-driven science instruction. A significant area of professional growth for Ms. Ly was that the CSP curriculum units provided her with a different model of project-based learning and phenomenon-driven science instruction than she had previously encountered. Selecting big ideas and anchoring phenomena is a core practice of science teaching (National Academies of Sciences, Engineering, & Medicine, 2015; Thompson, Windschitl, & Braaten, 2013). Ms. Ly described her original conception of PBL was to design a content-driven unit in which a project is introduced at the end that challenges students to "you have to use all this content that we already learned, and ideally you have mastered and applied it to this." As she became enculturated into the STEM Academy model of PBL, she began to understand how to introduce a project at the beginning of a unit as a way to build connections to the content, then allowing each day of instruction to unfold by continuing to make connections between the project and the content. Ms. Cruz noted that Ms. Ly needed support in being brought into the STEM Academy model of PBL and developed a framework tool to help communicate this vision and process of project facilitation (See Chapter Three for a discussion of this framework).

It can be argued that the CSP experience provided an expansive learning opportunity (Engeström, 2001) for Ms. Ly, as "it's opened up the variety of what project based learning could look like to me." The CSP biology units integrated phenomenon-driven science instruction with PBL and focused on a contemporary, unfolding scientific problem. With these two units, scientists are still developing their understanding of the links between climate change, Sea Star Wasting Disease outbreaks, and increasing rates of infectious diseases. These units did not introduce students to settled scientific concepts. Rather, Ms. Ly explained, "it's ongoing. It's like an investigation…they don't quite get that final, full explanation at the end." This was a game changer for Ms. Ly. She commented, "this is like an explanation. You have the most likely explanation based on the knowledge that you have right now, but it's not a fixed explanation. It's opened up the possibility of what project-based learning could look like." Her experience teaching the CSP units helped Ms. Ly understand how to help her students experience the uncertain nature of science, which is foundational to their understanding of the nature of science (Manz & Suárez, 2018). Ms. Ly couched this as "a necessarily uncomfortable place to be" in that "it's necessary, but it's not comfortable" to study a topic in which answers are not provided.

Ms. Ly also saw value in the authenticity of the scientific and computational practices in which students engaged during the units. She noted, "I think the applicability of this, saying how much is resembles what scientists is doing on the field. Having that connection to go back to every time that students question, 'Why are we doing this?' That felt successful." Ms. Ly also felt that the CSP's ability to connect students to "actual scientists who is working on the same topic" was beneficial to her students and something she had not had access to before. This included the CSP's sponsorship of a field trip to a local marine science center hosted by marine scientists, a virtual scientist visit in which two scientist answered students' questions, and having access to CSP researchers with backgrounds in evolutionary biology and marine biology.

Expertise with computationally-rich science instruction. Computational thinking (CT) is one of the eight NGSS Science and Engineering Practices, but there are few resources for science teachers for integrating CT practices and tools into their classrooms in meaningful and disciplinary-connected ways. The CSP's computational thinking (CT) framework (Weintrop et al., 2016) includes practices that enable students to engage in investigations of large, complex scientific phenomena, such as climate change and evolution. These computational inquiry practices include data practices (e.g., collecting, creating, and analyzing data), modeling and simulation practices (e.g., using and building computational models), and systems thinking (e.g., investigating complex systems, understanding relationships within a system, thinking in levels).

The two biology units that Ms. Ly enacted in her classroom were specifically designed to integrate these computational inquiry practices. The extended biology evolution unit engaged students in an interdisciplinary project in which they investigated the questions: *How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?* and *What can we predict about the future of the species, given warming trends in sea surface temperatures?* In this unit, *s*tudents worked in groups, taking on authentic project roles (e.g., geneticist, oceanographer, geographer, population biologist, and social scientist), to create an infographic that includes a geospatial model, line graph, conceptual diagram, a prediction, and recommended action steps. See *Appendix G* for an example of one group's final project from the biology evolution unit focused on Sea Star Wasting Disease. The second unit, a mini biology unit on infectious diseases, engaged students in a case study that posed the question: *Will deadly bird flu strains become more common with climate change?* Students took on authentic project roles (e.g., epidemiologist, virologist, health and safety engineer, and information scientist) to interact with, analyze, and represent data from a live tracking flu website and to develop a conceptual (causal-loop) model of factors that influence flu outbreaks.

Ms. Ly reported that through the experience of enacting the two computationally-rich biology units, her confidence in incorporating computational inquiry into her classroom grew in ways she could not have imagined. In fact, Ms. Ly identified “the computational piece” as one of her major professional take-aways from her involvement in the project. She noted that before her involvement in the CSP, it would not have occurred to her to incorporate computational thinking practices, noting “I wouldn’t have thought about it to do it myself for a unit”. Ms. Ly reflected,

> As far as doing something as a full blown analysis that they have to do with looking at data and making graphs, comprehending the meaning of those graph; that was something that I would not see myself doing before the unit.

Ms. Ly did not have any prior experience with integrating CT into her classroom other than using online simulations, so this was a major area of professional growth for her.

As a result of her CSP experience, Ms. Ly reported that she understood how to engage students in analysis of large data sets using computational tools—including spreadsheets and data visualization and modeling software—and systems thinking practices. As part of the two biology units, students engaged with CT tools such as Google sheets for analysis and visualization of large datasets, graphing and visualization programs, Google maps for creating geospatial models, live flu tracking websites, and other tools. Her experience inspired Ms. Ly to develop ways to incorporate CT practices and tools into her math class, in particular bringing in spreadsheets as a tool for data analysis. She commented, “You don’t use calculus in anything honestly, but you do use skill like Google sheet and making graphs, and just making things presentable.” In addition, she felt that systems thinking practices stuck with her students, noting that later while facilitating a concept mapping activity, her students suggested they employ systems thinking principles. Ms. Ly felt that these computational practices were transferable across disciplines and would serve her students in the future.

Although researchers and policymakers have advocated for the inclusion of computational inquiry practices, the use of computational tools, and the study of complex systems phenomena in the K-12 science curriculum (Jacobson & Wilensky, 2006; Sharples et al., 2015; Weintrop et al., 2016; Yoon, Goh, & Park, 2017), little is known about how to support teachers' learning and development of teacher expertise or pedagogical content knowledge for disciplinary practices (Yoon, Goh, & Park, 2017; Davis & Krajcik, 2005) that are specific to teaching computational practices. There is a need to understand how engagement in curriculum co-design focused on computational inquiry and complex systems phenomena, and the use of educative curriculum, may support teacher learning, pedagogy, and use of computational tools (Yoon, Goh, & Park, 2017).

A shift in teacher practice through PBL project work. It was not just her students who benefited from being introduced to computational practices and tools. Ms. Ly experienced a shift in her instructional practice as her biology students engaged in project work as part of the evolution unit. Ms. Ly ideally conceptualized herself as a *facilitator* of student learning. However, during much of the enactment, she was observed taking on the role of a *lecturer* who regularly relied on didactic, front-loaded instruction. During debrief sessions, Ms. Ly often seemed enthusiastically in support of student-centered instructional strategies that would place her in more of a facilitator role, however, as it would unfold in the classroom, she would often fall back to lecturing at the front of the room from her carefully prepared slide deck. It was often noted that she would frontload content or "skills" with students before allowing them to engage in activities, although curriculum materials were written so that students would encounter and make sense of subject-matter content through engagement in scientific practices. For example, before allowing students to engage in a sea star dissection lab, she spent the class period prior lecturing on lab safety, expectations, and dissection protocols. During the dissection, she demonstrated each step in the dissection at the front of the room before allowing students to try it out themselves, and then made all students wait until she was ready to move onto the next step in the dissection.

We did observe her take on more of a facilitator role, however, during students' work on the SSWD project, showing how PBL may structure teaching and learning in a way that encourages lecture-prone teachers to step back and let their students take the lead in their own project work. The project structure and embedded computational practices engaged students in authentic roles as they worked in teams to analyze and visualize data from large data sets, allowing them to leverage everyday expertise through self-guided learning and peer-teaching within groups and across roles. Ms. Ly developed a survey in which students could self-identify their areas of expertise with spreadsheets, so that other students could know who to ask in the room for help. These curricular structures intended to decenter the teacher as authority and knowledge-giver. In fact, answers to their queries of the data could only be developed over time as students engaged in data analysis practices. Researchers' analytical memos from this time in the enactment note their excitement as seeing students' leverage each other's expertise, engage in peer teaching, and increase peer-to-peer classroom discourse.

Ms. Ly acknowledged that she took on more of a facilitator role during project work, which matched her idealized vision of teaching. However, during an interview reflection, Ms. Ly worried about this approach, struggling with her urge for didactic teaching. As she reflected on these classroom moments, she shared that when students were peer-teaching during project work, she should instead have demonstrated some of the practices of using spreadsheets and had all the students practice the skill with her. She was not yet confident with how her conceptual image of teacher-as-facilitator would play in her own classroom.

Interestingly, rather than seeing the value of the project's structure and embedded instructional strategies and computational practices that allowed students to leverage each other's expertise, Ms. Ly credited her ability to step away from the front of the room during the SSWD project due to her own lack of content expertise with sea stars and SSWD. She reflected, "I think most of it has to do with because I didn't have like extensive knowledge on the topic, and that…I was able to pull back and let student take charge." However, when she enacted the CSP infectious disease unit later that spring, it was a topic in which she had expertise and deep interest, which for her actually served as a barrier to taking on a facilitator role. Ms. Ly explained her thinking,

> Whereas something, if I had like way more knowledge on, it's I feel like there's a force that I want to just keep pushing out knowledge. I was like, there's so much that I want to talk about. There's so much that I want to share that I'm just going to like keep talking on and on and on with students rather than letting them like discover things for themselves or doing or taking the ownership.

When she engaged in co-design of the influenza case study for the mini-unit, Ms. Ly went back to her notes from an undergraduate seminar on influenza and a research paper she wrote on influenza, leveraging her own professional resources to add to the project. Her excitement for the topic was palpable, though puzzling to some students. Ms. Ly shared that one of her students pointed out, "you just said you love influenza, the thing that kill a lot of people." Her love for the topic kept her in the role of lecturer, even though "consciously I want to be the facilitator." However, when the topic is something in which she holds expertise and interest, "I tend to do the opposite."

There appeared to be a mismatch between Ms. Ly's vision, intent, and actual classroom practice. This illustrates *the problem of enactment* (Kennedy, 1999 as cited in McDonald, Kazemi, & Kavanagh, 2013), a discrepancy between what novice teachers can be trained for and can conceptualize doing and what they are actually able to accomplish in the classroom. Although the PBL structure and computational practices of the SSWD unit project provided an opportunity for a shift in her practice, Ms. Ly had not yet developed the confidence, core practices, and pedagogical strategies to put her conceptual image of teacher-as-facilitator into regular play in her classroom. Facilitating learning opportunities, rather than transmitting knowledge to students, is a complicated instructional practice that takes time to develop.

Developing repertoires of practice for collaboration. A third area of professional learning for Ms. Ly grew out of CSP co-design practices. At first, Ms. Ly did not characterize the co-design activities she participated in with researchers as curriculum design, sharing that she felt she had not contributed much to the process and did not feel much ownership as she "didn't create it myself." She had spoken to Ms. Eider and Mr. Sherman about the co-design approach used in Year One of the CSP, learning about our first approach to co-design in which these teachers met with researchers for thirteen in-person design sessions to collaboratively design a chemistry unit. Due to the teachers' preferences, this resulted in a skeletal instructional plan, with multiple choices of activities and optional resources. Through that process, researchers learned that co-design with early-career teachers required specific kinds of routines, practices, and tools. Therefore, we pivoted and implemented a different co-design approach for the biology materials, where the lead authors of the two biology units were researchers, each with relevant professional backgrounds as biologists.

Over time through her enactment of the units, Ms. Ly recognized the design work inherent in the cycles of design-feedback-adaptation between herself and the research team. The researchers shared drafts of curriculum materials with Ms. Ly for her feedback. This back and forth allowed Ms. Ly to make suggestions on the curriculum materials, with her lens centered on student interest. She then took the provided curriculum materials and engaged in local adaptation for her own classroom, planning out instruction for her two biology classes. She described this process as being provided with a curriculum, but with a "collaborative piece on the side." She contrasted this process to what it is like to be provided with a textbook or off-the-shelf curriculum, noting that the CSP units were more flexible, adaptable, contemporary, and authentic than a more traditional district-provided curriculum would have offered.

Moreover, the CSP co-design model included almost daily debrief sessions, where Ms. Ly received feedback from myself and Ms. Cruz based on our observations of instruction. Ms. Ly described the collaboration within the CSP as "a process of communication" in which she received feedback on her enactment of the lesson plans in one of her class periods, and then she made micro-adaptations to improve instruction for her other class period while the researchers also made changes to the curriculum materials. Together, she saw our collaboration as creating a better version of the curriculum for her students, and ultimately, for others upon its eventual publication. The collaborative design practices in the CSP provided an opportunity for Ms. Ly's to expand her own definition of collaboration.

The literature on in-service teacher learning is in agreement that teacher professional learning should occur through collaboration (Ball & Cohen, 1999; Ford & Youngs, 2017; National Academies of Sciences, Engineering, & Medicine, 2015; Newmann, Krus, Louis, & Bryk, 1994). Design-RPPs provide a context for early-career teachers to develop repertoires of practice for collaboration with experts outside of the school building (Voogt et al., 2015) which could provide a form of social network for these teachers (Penuel, Bell, Bevan, Buffington, & Falk, 2016).

Advice Network and Social Supports

Ms. Ly seemed capable of forming professional relationships that allowed her to develop her social network (Penuel, Bell, Bevan, Buffington, & Falk, 2016) and advice network (Baker-Doyle, 2011), in particular for content and instructional support. As a first year teacher at STEM Academy, she noted that many teachers checked in with her regularly. As a first year teacher, she was able to observe Ms. Eider's chemistry class before teaching the same lessons in her own classroom the next day and Mr. Sherman shared curriculum resources with her. At Cascade STEM School, she sought advice, mentorship, teaching resources, and insights on her students from her fellow teachers in the building. Ms. Ly explained, "I come to all the teachers just around to ask question when I need anything." Ms. Ly's new classroom at Cascade STEM School was located across the hall from an experienced science teacher, who became an important person in her advice network. Ms. Ly explained,

> So anytime that I was banging my head against the wall, trying to come up with an activity that would help deliver the material that I want to deliver to the students at the level of depth - like not too shallow, not too deep—I kind of came to him—I could just come to him and ask and he would almost guarantee that he has something to offer.

This more-experienced colleague became a reliable person in Ms. Ly's advice network. When Ms. Ly was asked to teach a math course her first year in addition to chemistry, she sought help from a content specialist as well as all the other math teachers at the school. For new teachers, an Intentional Professional Network consisting of their professional colleagues at school helps them "navigate the norms of their school, establish their status and professional identity, solve everyday problems, and feel more confident about their work within the school building" (Baker-Doyle, 2011, p. 22).

In addition to her teaching colleagues, Ms. Cruz also became a critical member of Ms. Ly's advice network. Ms. Cruz's role was to provide instructional coaching to all the science and math teachers, however the CSP positioned her in particular in a mentorship role with Ms. Ly. During the enactment of the biology evolution unit, Ms. Ly and Ms. Cruz engaged in co-planning, co-teaching one class period together four days a week, and almost daily debriefs of instruction. Data from these debrief sessions show how Ms. Cruz regularly resourced Ms. Ly with instructional resources. Ms. Ly also recognized the value of having Ms. Cruz as a co-teacher in one of her biology class periods, as well as her broader contributions to the CSP partnership, commenting,

> The support having [Ms. Cruz] being the liaison between the [university] group and me and the kid, that's something I'm really happy about too. And especially being a new teacher, and having [Ms. Cruz] being a more experienced teacher in the classroom, I think that's gonna help the experience for the kid a lot richer. And she can also help a lot with the classroom management too, especially that's something that I'm still working on.

Ms. Ly recognized Ms. Cruz's boundary spanning role within the CSP partnership, in particular, the ways that she acted as a communication conduit with the university-based research team and supported the unit enactments.

Outside of the school building, Ms. Ly identified the CSP research team as a source of advice and support. She noted in particular an appreciation for the open "line of communication" that existed between herself and the CSP researchers, noting that when she pushed out an email with a question, she would usually get a response from the research team the same day or the next. Ms. Ly identified this reliable communication style as "something that I'm really happy about." This open line of communication allowed Ms. Ly to leverage the diverse expertise of the research team. For example, when she had specific content questions related to a lesson activity her questions were quickly answered by the lead author of the curriculum unit, a member of the research team who was trained as an evolutionary biologist. The routine of the co-design and planning process also allowed Ms. Ly to tap into the curriculum design and pedagogical expertise of the researchers as she planned her local adaptations to the curricula.

The CSP partnership also provided Ms. Ly with much needed curriculum materials for her science classes. She noted that her teaching colleagues were her only source of curriculum materials, other than a provided math textbook, as nothing else was provided by the school or district. She noted, "so that's pretty much all that I would have without you guys for as another resource that I can go to. So, yeah definitely knowing that I can go to you guys with questions and knowing that you guys are experts in the field is definitely been a plus." Additionally, Ms. Ly expressed gratitude for the professional resources that were offered to her by the research team. She felt that the relationship pushed her toward seeking out more evidence-based teaching strategies. For example, in debrief sessions I shared with her practice briefs that introduced science talk strategies and also arranged a virtual call with a former special education teacher to help her think through ways to support the special education students during project work. During classroom observations, I noted Ms. Ly immediately incorporating some of these strategies. Ms. Ly cited this type of resourcing from the research team as helpful to her developing practice.

One potential source of support in Ms. Ly's professional life that was absent from these conversations was support from district staff and her administration team. She noted that during her first year at STEM Academy, her principal had specifically positioned her to teach chemistry to tenth and eleventh grade students, who were considered to be "an easier cohort" than the ninth grade cohort as they already had a culture established. At Cascade STEM School, she found the new administration team to be “not as relatable”, and that with the move to the larger school, there was “not as much love and care” directed at her as she had previously experienced at STEM Academy. In general there was no longer “the same family feel that originally had drawn me to the school”. Ms. Ly’s comments were tinged with a tone of sadness over the loss of STEM Academy’s school culture.

The relationships that Ms. Ly developed within the CSP partnership are an example of her Diverse Professional Allies (Baker-Doyle, 2011), individuals who made up her professional social network outside of the school building. Diverse Professional Allies—such as the CSP researchers—may provide “boundary-crossing ties” and may help a new teacher develop innovations, challenge norms, and leverage community resources and support (Baker-Doyle, 2011). In addition, by extending their social network to outside of the school building, teachers may benefit from the stimulus provided by new information and expertise (National Academies of Sciences, Engineering, and Medicine, 2015).

Ms. Ly’s advice network also extended to three other Diverse Professional Allies: her university mentor from her certification program and her TfA mentor and program director. These allies provided her with career advice and emotional support. Ms. Ly felt that these individuals were supportive and expressed deep care for her. However, despite Ms. Ly’s ability to develop an advice network inside and outside of the school building, the emotional labor of teaching became a heavy burden.

The Emotional Labor of Teaching

Reflecting on her second year of teaching at the new Cascade STEM School, Ms. Ly described it as “all this chaos.” There was a new school, new administration, new policies, new colleagues, and new students. She was also teaching both a science and a math course, and this was her first time teaching a biology course. In particular, she was shocked by the behavior of some of her students in class and upset by all the “outrageous things” that students would say to her in front of the whole class. Ms. Ly encountered multiple instances of microaggressions from several male students, including racially-charged remarks directed at her. She noted that when she was growing up in Vietnam, teachers were respected and treated differently than her experience in the U.S.

Ms. Ly cared deeply for her students, but she worried that she might “ruin them” as an inexperienced teacher. Many of her students felt that care, reporting in letters they wrote to her during the last week of school that she was patient, caring, and loving. However, Ms. Ly felt uncertain if she would be able to maintain that level of care over time. She also worried that she would be unable to sustain her passion for teaching, noting that it would become “hell if you don’t love what you do”. In her final interview, Ms. Ly divulged the many times that she had cried during the school year, including the day a student told her he hated her; her emotional devastation left her unable to teach her class the following period. Looking forward, Ms. Ly could not see herself “being able to care as much as I do now” and felt that “at some point it’s not worth that much emotional investment.” After two years of teaching, Ms. Ly was emotionally exhausted and spent. Rather than renew her contract and continue past her TfA commitment, she chose to resign and leave the teaching profession. Teaching through TfA became one brief stop along her career trajectory.

Chubbuck and Zembylas (2008) report a similar trajectory in their case study of a novice, urban teacher who cared deeply about socially just teaching. This teacher navigated through her own complicated emotional landscape, and at the end of her first year of teaching, resigned from her position to pursue a different career trajectory. These authors highlight the importance of centering research of novice teachers on emotions, including their expressions and navigation of emotions, for they note, “emotions are powerful forces in teaching that warrant attention” (Chubbuck & Zembylas, 2008, p. 277). They report that “emotionally laden stress and burnout are considered among the most important factors that lead many teachers to abandon the teaching professions” (Chubbuck & Zembylas, 2008, p. 277).

Risks to Potentially Vulnerable Novice Teachers

At times, I, along with the other researchers at times, were concerned about the impact of CSP participation on Ms. Ly, and the potential pressures and asks of time—especially as a second year teacher. However, Ms. Ly did not link her emotional exhaustion to her involvement in CSP activities. She reported that having researchers, video cameras, audio recorders in her classroom and wearing a microphone did not phase her. Rather, she noted her appreciation for the support the partnership offered her. She identified this support as involving things she would never have gotten outside of the CSP partnership, including having access to Ms. Cruz as a co-planner and co-teacher, funding and logistical coordination for a field trip, and people with deep expertise on the topics she was teaching about who would quickly respond to her email messages. She also noted that given that she was not provided with curriculum materials from the school or district for her science and math courses, the CSP played an important role. It supplied her with much-needed curriculum and support while enacting the units. As a new teacher, Ms. Ly recognized the luxury of having at times four adults in her classroom during the biology evolution unit enactment. She was also financially reimbursed by the CSP for time spent on project activities outside of the school day. Ms. Ly felt that “the type of support that you guys provided I think is going to be super helpful for a new teacher who actually needed those kind of support."

However, though Ms. Ly did not indicate that she felt any hardship caused by her participation in the CSP, she acknowledged that it could feel that way for other teachers, especially novices. She theorized that involving new teachers in a partnership like the CSP could be difficult, "because you are trying to put something new on a new teacher who's having to do with, like deal with so many other immediate tasks that they have to put their focus and attention on." This point is important, as Ms. Ly considers the complex layers of professional learning encountered by a novice teacher. However, she did say she would recommend an experience like the CSP to other early-career teachers, but acknowledged the importance of context for this type of co-design and enactment work. Ms. Ly reflected that the school merger impacted how the unit played out during enactment. She felt that there was so much uncertainty about the school and students that the CSP project created "an even bigger unknown to add to my unknown pool." Although she would recommend a co-design initiative like this to other early-career teachers, she would not recommend it if the school itself was undergoing a major transition or transformation that introduced various structural and cultural barriers to the work. Ms. Ly's comments point toward the importance of researchers being sensitive to contextual, personal, and professional factors that may make an early-career teacher particularly vulnerable to risks introduced by participation in a design-RPP—such as pulling their attention away from developing their own professional practice and nurturing their social networks within the school building.

Discussion and Implications

The case study of Ms. Ly presented in this chapter sought to answer the question: *How did the involvement of an early-career science teacher in co-design, local adaptation, and* *reflective enactment of curricula benefit and challenge her professional learning, development of various forms of expertise, and professional practice?* The case of Ms. Ly shares her own reports of professional learning and changes to professional practice through involvement in the CSP. In order to answer my second research question, we need to think more broadly beyond Ms. Ly's own thoughts to consider the practicality, benefits, and risks of engaging early-career teachers in these kinds of intensive curriculum design and enactment practices through partnership. I questioned: *Should early-career teachers be asked to take on critical partner roles in design-RPP endeavors?* This question goes beyond considering the benefits and risks to the novice teachers with whom we partner to also consider the impacts to the design-RPP as an organization. In this section, I assert that design-RPPs can serve as professional learning contexts for early-career teachers, but caution researchers to take care when partnering with schools that largely employ early-career teachers, ask their science faculty to also teach math outside of their certification, or are experiencing mergers, moves, or expansions. As part of this, I summarize some of the more broad benefits and challenges of partnering with early-career teachers in this complex partnership work.

Design-RPPs as Contexts for Teacher Learning

This case study suggests that a design-RPP can function as a context for teacher professional learning and development of multiple forms of expertise, including pedagogical expertise with computational practices and tools. Ms. Ly's own professional learning pathway toward this expertise included her participation in activities of co-designing, co-planning, co-teaching, and instructional debriefings with support that would not have been available to her outside of the partnership. She identified the types of support she received as also including collaboration, financial support, structures for reflective practice, communication, access to scientists, practical pedagogical tools and resources such as science talk strategies, as well as conceptual tools such as systems thinking. Her participation in the partnership also inspired her to look to evidence-based teaching strategies. In some ways, the design-RPP functioned as a social network for the teacher (Baker-Doyle, 2011), resourcing and supporting her in ways her colleagues and administrators could or did not. The context for this learning—the activity structures and relationships afforded by the design-RPP—are different than what Ms. Ly would have normally had access to in her school building.

Teachers engage in professional learning across different contexts and across the temporal trajectories of their careers. For example, McDonald, Kazemi, and Kavanagh (2013) proposed a cycle for pre-service teacher professional learning that can take place across controlled, designed, and authentic settings. Extending this idea of settings for teacher professional learning, when in-service teacher professional learning occurs through co-design activities within the context of a design-RPP, the structures and supports provided by the partnership form a different kind of context. I call this a *designer setting*, in which a teacher's professional learning pathway includes additional ways of implementing the learning cycle that are unique to co-design work. With a designer mindset and the role of critical partner, a teacher engages in collaboratively designing curricula, planning, teaching, debriefing, and revising curricula, all in partnership with and with support from university researchers, disciplinary experts, and project staff. This is uniquely different from other pre-service and in-service professional development opportunities.

Teacher Learning in a "Designer" Setting: Benefits for Novice Teachers

The teacher at the focus of this case study encountered institutional, cultural, philosophical, and emotional challenges to her professional learning. Her attempts to navigate through these barriers were captured during classroom observations, teaching debriefs, and reflective interviews. As a new teacher, she reported that her professional learning pathway, including her TfA training and alternative certification program, left her feeling ill-prepared for the realities of classroom teaching. Though she expressed a deep sense of caring for her students, she also revealed the emotional and physical exhaustion of being an early-career teacher that experienced "all this chaos" surrounding the move to a newly merged school. She ultimately chose to leave the teaching profession after completing her Teach for America service. However, she reported that the design-RPP provided her with support outside of what her colleagues and administrators could,

Similar to Ms. Ly's case, another teacher at STEM Academy that was involved in co-design activities in Year One and Two of the CSP emphasized in his interviews the benefits of participating in the CSP as an early-career teacher. Mr. Sherman was involved in co-design activities in Year One of the CSP as a student-teacher at STEM Academy and then enacted the chemistry unit in the autumn of his first year of teaching during Year Two. He noted during an interview with me that participating in the project had been beneficial for him as a novice teacher. Before launching the unit enactment, he predicted that participation in the CSP would help him to be more successful due to the high level of support provided. Later, after wrapping up the unit enactment he stated that it would have been "exceptionally difficult" to feel prepared for his chemistry course if he had not had access to the CSP curriculum materials and resources as well as chemistry labs and handouts provided by Ms. Cruz. Mr. Sherman talked about the benefits of having a member of the research team who provided in-class support during his lab periods as being "really, really helpful. Invaluable." He revealed that he did not know how teachers at other schools with larger class sizes navigate lab activities, acknowledging the value of the extra adult in the room that was provided by the CSP. Mr. Sherman also reflected on the higher level of accountability that he feels as part of the project team, describing it as "motivating." Mr. Sherman reported the benefit of feeling that he could tap into help from the CSP researchers if he needed it. These supports, as well as his own familiarity with chemistry content and his chemistry endorsement, all contributed to him feeling "less stressed" about his chemistry class than his math classes.

During his involvement in CSP co-design activities, Mr. Sherman reported that it was "an adjustment to recognize that my opinion is valued" as he made important contributions to the design process, in particular leveraging his chemistry content expertise. He stated that the CSP project was a "cool opportunity" and that these types of opportunities are not often available to first year teachers. Mr. Sherman did note that he appreciated that Ms. Eider's class was chosen as the focus for data collection activities and that he may have felt differently about the experience if researchers had been filming in his chemistry class. Mr. Sherman's caution is an important one for researchers to note; intensive data collection activities—including daily classroom observations and the use of video cameras and microphones—have the potential to create an intimidating atmosphere for a first year teacher.

Teacher Learning in a "Designer" Setting: Cautions for Partnering with Novice Teachers

As Ms. Ly and Mr. Sherman's interview responses indicate, while early-career teachers themselves may see great value in participating in a co-design initiative and benefiting from the support of a partnership that extends outside of their school building, researchers need to proceed cautiously. As attrition rates show, it is important to recognize that early-career teachers are vulnerable. Of the three teacher-designers involved in the CSP—Ms. Ly, Ms. Eider, and Mr. Sherman—two left the teaching profession after their second year. Contributing factors to Ms.

Ly and Ms. Eider's decisions to leave the profession included emotional exhaustion and teaching burdens (e.g., never teaching the same course, not being provided with a curriculum, and being assigned to teach math outside of their certification and training).

Though teacher retention literature emphasizes the importance of providing coaching, mentoring, and supportive learning opportunities for newly in-service teachers, researchers must consider if their design-RPP is capable of providing these specific types of support. Researchers must consider if providing supports to novice teachers will distract from the goals of the design work or will impact the quality of the designed curriculum products, especially if it is intended to be disseminated broadly. While working with early-career teachers offers benefits to the project, such as their openness to new ideas and pedagogies, researchers should also consider the advantages of partnering with experienced veteran teachers with deep professional expertise.

As described in Chapter Five, the CSP team saw a need to partner with more experienced teachers during two points in the design process for the biology evolution unit. First, early in the design process, we engaged two veteran biology teachers from a different district to co-design initial ideas for the unit and enact them in their classrooms; this was before we settled on the anchoring phenomenon for the unit. Second, after Ms. Ly enacted the unit in her classroom, we engaged a veteran biology teacher to enact the computational project from the unit with her students so that we could learn how the project unfolded when facilitated by a more experienced teacher and in a different school setting.

Not all design-RPPs will be willing to or capable of supporting early-career teachers' development of practice in addition to engaging teachers in design work. One option to explore could be inviting early-career teachers to take on collaborator roles in partnership with more experienced teachers at their same school, if that is possible, rather than being tasked with leadership roles, as Ms. Ly, Ms. Eider, and Mr. Sherman were. For example, at STEM Academy, CSP researchers began to forge a relationship with a more experienced engineering/technology teacher who offered expertise in computational practices and tools; however he chose not to transition to Cascade STEM School upon the merger and therefore exited the collaboration. If the partner school's faculty does not offer that possibility, then researchers could explore partnering with teachers from multiple schools.

Opportunities for Future Research

New science teachers are expected to: understand the content and disciplines of science; understand learners; understand instruction, curriculum and assessment; understand learning environments, including classroom management; and become a professional, including becoming part of a professional community, developing a professional identity, and developing a sense of self-efficacy (Davis, Petish, & Smithey, 2006). Design-RPPs can be considered as a context for teacher professional learning, which may provide some opportunities for teachers to expand their understanding across these areas.

Ms. Ly's case of an early-career teacher taking on a leadership role within a design-RPP opens up other opportunities for research. The coaching practices that developed between Ms. Cruz and Ms. Ly could be examined to understand more fully the types of supports she was provided. The methodology of portraiture (Lightfoot, 1983) could be implemented to develop descriptive accounts of Ms. Ly in her biology classroom, which could include contrasting her instructional practices before, during, and after the supported enactment of the biology units.

Ms. Ly's single case study could also be contrasted against Ms. Eider and Mr. Sherman's experiences with the design and enactment of the chemistry unit, providing a cross-case analysis (Merriam & Tisdell, 2016; Yin, 2014). With this broader view across the three teachers, it could be helpful to understand how a design-RPP might offer a setting for early-career teachers to access resources and tools for curriculum design, reflective practice, craft knowledge, and disciplinary knowledge, thereby expanding their "horizon of observation" (Hutchins, 1995). A broadening of the horizon of observation for an early-career teacher can increase the teachers' ability to have access to other people, and their ability to "see, hear, and participate in the work in question: its central tasks, tools, and instruments, relevant categories and terms, and lines of communication" (Little, 2003, p. 917). Ms. Ly's case revealed that her experiences enacting the CSP biology curriculum expanded her conceptions of what and how to teach, in particular the use of computational tools like spreadsheets and the inclusion of unfolding and unsettled contemporary scientific phenomena. Further investigations of design-RPPs as contexts for professional learning for early-career teachers could consider how being part of these types of collaborations might expand teachers' conceptions of what content, practices, and tools to bring into their practice and might even disrupt patterns of teaching—instilled by their own experiences as students, teacher preparation programs, alternative certification programs, or mentor teachers—by offering new pedagogical models and strategies.

Conclusion

A design-RPP can function as a context for teacher professional learning and development of multiple forms of expertise, including pedagogical expertise with computational practices and tools. The focal teacher's own professional learning pathway toward this expertise included her participation in activities of co-designing, co-planning, co-teaching, and instructional debriefings with support that would not have been available to her outside of the partnership. In some ways, the design-RPP functioned as a social and advice network for the teacher (Baker-Doyle, 2011), resourcing and supporting her in ways her colleagues and administrators could or did not. Further research is needed to understand how to structure design-based RPPs to create a supportive *designer setting* for teacher professional learning that provides professional, social, and emotional supports.

This work contributes insight into teacher professional learning that occurs through co-design, with a focus on developing pedagogical expertise in the design and use of computational practices and tools. We must think beyond the design of better curricula to the impacts that engagement in co-design may have on teachers' professional learning and practice. Further research is needed to understand how to structure design-based RPPs to create a supportive *designer setting* for teacher professional learning. In particular, the research community needs to study the risks and benefits of involving early-career teachers in co-design initiatives.

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Chapter 5: Navigating Tensions in Co-Design through Knotworking: Selecting Contemporary Scientific Phenomena for High School Biology Curriculum

Introduction

The *Framework for K-12 Science Education* (National Research Council, 2012) suggests that equitable three-dimensional science and engineering instruction should be driven and anchored by scientific phenomena or engineering design problems. These phenomena and design problems should be authentic, real world, and relevant to students' own lives and interests (National Research Council, 2012). Students engage in the three-dimensions of science learning (e.g., Disciplinary Core Ideas, Scientific and Engineering Practices, and Crosscutting Concepts) in order to investigate, understand, and explain scientific phenomena (Achieve, et al., 2016). The argument for phenomenon-driven science instruction in the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) is based on the claims that:

- "Anchoring learning in explaining phenomena supports student agency for wanting to build science and engineering knowledge" by helping students understand why they need to learn scientific concepts and practices.
- "By centering science education on phenomena that students are motivated to explain, the focus of learning *shifts from **learning about** a topic to **figuring out** why or how something happens*" which can lead to "deeper and more transferable knowledge."
- "Students who come to see how science ideas can help explain and model phenomena related to compelling real world situations learn to appreciate the social relevance of science" which can "help sustain students' science learning" (Achieve, et al., 2016).

The *Framework* recommended shifts in how to design and enact science instruction that included anchoring instruction with authentic scientific phenomena. However, at the time its publication, there was little guidance from the research community and few available resources for understanding how to identify and select anchoring phenomena and how to design and enact phenomenon-driven curriculum and assessments. Over the past few years, we have seen additional resources being developed and disseminated (e.g., STEM Teaching Tools, professional development modules from Advancing Coherent and Equitable Systems of Science Education (ACESSE), and NextGenStoryLines). Despite the addition of these resources, there continues to be a need for tools to understand how to engage in a process of selecting anchoring phenomena for curriculum design and science instruction.

In this chapter, I share the processes and experiences of the Computational Science Project[4] (CSP) partners as we selected an anchoring phenomenon for the design and enactment of a high school biology unit that integrated the scientific concepts of climate change and evolution with the practices and tools of computational inquiry. The CSP was a design-focused research-practice partnership (design-RPP; Coburn, Penuel, & Geil, 2013) funded through the National Science Foundation's STEM + Computing (STEM+C) program that developed computationally-rich curricula for high school science classes. The project engaged culturally and linguistically diverse high school students in the investigation of real-world, contemporary scientific topics using computational models, analyses of large data sets, and systems thinking, aligned with the new vision for science and engineering education laid out in the *Next Generation Science Standards* (NGSS Lead States, 2013). This chapter features a qualitative design narrative of how the members of the CSP engaged in the collaborative practice called

[4] A pseudonym.

knotworking (Engeström, 2008) and other activity structures to negotiate a particular design tension in their co-design work: how to choose between many possible scientific phenomena for a curriculum unit. As such, I sought to understand: *What processes and criteria for phenomenon selection should be used for the design of high school biology curricula? In particular, what selection criteria and processes of selection would support the design of curricula focused on a contemporary, locally-relevant, and computationally-rich scientific phenomenon that engages students in the socio-scientific issues of global climate change and evolution?*

Conceptual Framework

Our lens for developing criteria for how we would select the scientific phenomenon for the biology unit was influenced by the history of our research group's prior work in collaborative approaches to curriculum design and design-based research (Bell, Hoadley, & Linn, 2004; The DBR Collective, 2003), and grounded in a sociocultural view of learning (Rogoff, 2003). Our thinking about student learning and development was guided by the Cultural Learning Pathways Theoretical Framework (Bell, Tzou, Bricker, & Baines, 2012), which seeks to highlight "relevant dimensions of how, where, and why people learn" (p. 271). I will first describe concepts that informed curriculum design within the research project, including phenomenon-driven science instruction, and computational thinking. I will then discuss concepts related to our collaborative approach to curriculum design and Tatar's (2007) design tensions framework as a way for thinking about the tensions that emerge in design work. Finally, I will describe the concept of knotworking (Engeström, 2008), which was employed as a strategy for understanding how the group negotiated the design tensions associated with phenomenon selection for the curriculum unit. Knotworking in particular became a key analytical concept for this study.

Phenomenon-driven Science Instruction

A brief history. The new vision for K-12 science education outlined in the *Framework* (National Research Council, 2012) requires that teachers use scientific phenomena to drive or anchor instruction; however, this is not a new concept. Going back to the Separation and Integration Periods of science education spanning 1870-1975, natural scientists wrote textbooks, often in isolation from science educators or educational psychologists, which featured the phenomena and scientific breakthroughs that they themselves studied in their labs (Linn, Songer, & Eylon, 1996). More recently, phenomenon-driven science instruction has roots in different pedagogical approaches, including anchored instruction, project-based learning, and problem-based learning. Anchored instruction (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990) is an approach in which the teacher uses an anchor material—such as a video excerpt from a popular film—as an engaging, shared experience that presents a challenge to be solved. Problem-based learning (Hmelo-Silver, 2004), an educational approach first seen in medical schools in the 1960s, challenges students to work in collaborative groups to investigate complex, real-world problems. Project-based learning has roots extending back to educators and philosophers who believed in a hands-on, learning-by-doing approach, including Jean Piaget, Jerome Bruner, Maria Montessori, Lev Vygotsky, and John Dewey. In project-based learning, students are engaged in extended, student-centered, open-ended, collaborative, and often interdisciplinary investigations of a driving question through projects that culminate with an end product (Blumenfeld, et al., 1991; Krajcik & Blumenfeld, 2005). Over time, researchers, curriculum designers, and teachers have wrestled with how to select phenomena and design learning activities that are anchored by scientific phenomena (e.g., Linn, Shear, Bell & Slotta, 1999; Shear, Bell, & Linn, 2004).

Some researchers have argued that equitable science education needs to focus on ways to elicit, connect, and build upon students' interests (Bricker & Bell, 2014), everyday expertise (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2012; Zimmerman & Bell, 2012), and disciplinary identities (Bell, Tzou, Bricker & Baines, 2012; Bell, Van Horne, & Haugan Cheng, 2017; Bricker & Bell, 2012; Van Horne & Bell, 2017) in order to develop meaningful experiences for *all* learners (Rodriguez, 2015). Carefully selecting scientific phenomenon along these lines to anchor instruction has potential an equity strategy.

The recent consensus report *Science and Engineering for Grades 6-12: Investigation and Design at the Center* (National Academies, 2019) puts forth a design principle that scientific investigations and engineering design challenges in instructional materials should feature phenomena or problems that are personally relevant to students in order to increase engagement, interest, and motivation for learning. Personal and cultural relevance can be achieved by selecting locally-relevant phenomena (e.g., place-based education) or human problems, allowing for students' to choose phenomena to investigate that are personally relevant, and making explicit connections between the phenomenon and students' own lives and communities (National Academies, 2019). Moreover, in order to be contextualized and relevant, the scientific phenomena need to include "a connection to learners' interests, such as their communities, cultures, places, and experiences, and to real world issues" (National Academies, 2019, p. 112). Another recent consensus report, *Learning through Citizen Science: Enhancing Opportunities by Design* (National Academies, 2018), also investigated how citizen science projects—which position students as developing experts engaged in authentic practices of science in their own communities—can engage students in the investigation of locally-relevant phenomena. In subsequent paragraphs, I will describe a specific class of scientific phenomena for K-12 science education that focuses on contemporary scientific discoveries and will explain how phenomena are commonly differentiated in curriculum as anchoring, investigative, and everyday phenomena.

Classes of NatureCultural phenomena. Suárez and Bell (2019) argue that different classes of what they call NatureCultural phenomena should be featured in reform-oriented science instructional materials. They define the emerging idea of NatureCultural phenomena as those scientific phenomena that are "culturally meaningful", that provide students with "open opportunities for deep disciplinary sense-making", and which are grounded in a lens of equity and justice (Suárez & Bell, 2019). NatureCultural phenomena can be distinguished into four types: culturally significant phenomena, societally relevant phenomena, everyday phenomena, or contemporary scientific phenomena (Suárez & Bell, 2019). The high school biology curriculum unit featured in this chapter was categorized by Suárez and Bell (2019) as an example of a contemporary scientific phenomena.

Contemporary scientific phenomena. Suárez and Bell (2019) describe the class of contemporary scientific phenomena as having the following characteristics: "(a) investigated by professional scientists; (b) support youth [to] understand the situated, collaborative efforts associated with techno-scientific projects; and (c) can support youth [to] understand and address global, local, and ecological challenges."

Curricula that feature contemporary scientific phenomena may be a strategy for expansive, equity-focused science instruction that seeks curriculum topics and experiences that are relevant to students' lives, backgrounds, interests, and communities. The *Framework* (National Research Council, 2012) asserts that in order to be prepared to engage in all spheres of personal and public life—and to possibly pursue STEM careers—all students "should be able to frame scientific questions *pertinent to their interests*, conduct investigations and seek out relevant scientific arguments and data, review and apply those arguments to the situation at hand, and communicate their scientific understanding and arguments to others" (p. 278; emphasis added). Contemporary scientific phenomena are a context for engaging students in an exploration of the intersection between scientific advances and societal needs and impacts, through a form of epistemic action that Brante (1993 as cited in Bell, 2004) calls *science-based controversies*, which are also known as *socio-scientific issues*. For example, students can explore contemporary phenomena that are situated in ongoing socio-scientific controversies such as genetic engineering, nuclear energy, and global climate change (Morrison, Bell, Chowning, & Klein, 2017; Van Horne & Bell, 2014). Contextualizing contemporary science phenomena within social, cultural, ethical, economic, environmental, political, and historical dimensions may expand students' conception of what science is, who engages in it, and for what purposes. It shows science as relevant, dynamic, and unfolding—and draws connections between the contexts of students' lives at school, home, and in their communities, and with what they see in media (Bell, 2004).

The inclusion of contemporary scientific phenomena in the science classroom is also a way to make the nature of science more visible to students. Scientific controversies (Brante, 1993 as cited in Bell, 2004) are integral to how scientists go about engaging in their research, sharing their findings with their peers, and engaging in collaborative sensemaking of scientific advances over time. Bell (2004) argues that while most scientists devote their time to advancing knowledge, an act in which "controversy in all its forms is more the rule than the exception", K-12 science curricula have neglected to include scientific controversies—both historical and contemporary (p. 234). Inviting students to investigate contemporary scientific phenomena provides the opportunity for students to engage with the unsettled, unfolding nature of scientific inquiry (Bell, 2004) and provides opportunities for them to experience uncertainty in science (Manz, 2018; Manz & Suárez, 2018).

As an example, Bell (2004) described the inclusion of contemporary scientific controversies and socio-scientific issues in K-12 classrooms as part of the Science Controversies Online Partnerships for Education (SCOPE) Project. This project resulted in the development and study of three science curriculum modules, each anchored by a scientific phenomenon (see also Linn, Shear, Bell & Slotta, 1999; Shear, Bell & Linn, 2004). Bell (2004) described some of the characteristics of one of these modules, focused on deformed frogs, as being: a surprising phenomenon that students found compelling; a timely issue that was the subject of scientific publication and media reports; represented a multidisciplinary pursuit by scientists; the subject of competing theories to explain the phenomenon; a smaller piece of a larger, complex issue (i.e., global declines in frog populations). In addition, the underlying scientific concepts were well connected and central to understanding broader biological concepts and therefore met the teachers' instructional needs (Bell, 2004). It is also worth noting that the unfolding phenomena of deformed frogs across North America was brought to the attention of the media by a group of seventh grade students in Minnesota after their own field studies in 1995 discovered deformities in frogs (Linn, Shear, Bell, & Slotta, 1999), showing the power of citizen scientists to bring attention to a local issue. As seen in this example, the investigation of contemporary scientific phenomena that embed scientific controversies and socio-scientific issues has the potential to connect to students' interests, to demonstrate the unfolding and uncertain nature of scientific understanding, to engage them in the work of professional scientists and engineers, and to better prepare them as citizens of a complex, demanding, and increasing scientific and technical world.

Types of phenomena. Phenomena may be employed in different ways during the design of instructional materials and the enactment of classroom instruction. It is helpful to consider different types of phenomena for these curricular purposes: anchoring, investigative and everyday (Achieve, et al., 2016). An *anchoring phenomenon,* along with its driving question, is used to anchor and focus an entire unit of instruction. This type of phenomena has roots that trace back to the anchored instruction approach of the 1990s (Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990). Phenomena chosen to anchor instruction should be aligned to one or more NGSS performance expectations. *Investigative phenomena* are similar to anchoring phenomena but are used at the lesson-level (or sequence of lessons) to engage students in investigations and sensemaking that make up the Disciplinary Core Ideas related to the anchoring phenomenon. Through engaging in explorations of lesson-level investigative phenomena, students develop understandings that build toward an understanding of the anchoring phenomenon. *Everyday phenomena* are those that "relate investigative or anchoring phenomena to personally-experience situations" (Achieve, et al., 2016). The use of everyday phenomena has its intellectual roots in Marcia Linn's work with prototypes—everyday examples of scientific phenomena—from the 1980s and 1990s (Linn & Hsi, 2000). Problematizing these everyday phenomena is one strategy for igniting students' curiosity and interest when engaging them in questioning and investigating the things they routinely see and experience (National Academies, 2019).

It is important for science educators and curriculum designers to understand how to select quality scientific phenomena for the design of phenomenon-based science instruction. Indeed, selecting big ideas and anchoring phenomena may be considered as a core practice for science educators, especially for novice science teachers who may need support in understanding how to select scientific phenomena to anchor instruction (McDonald, Kazemi, & Kavanagh, 2013). However, since the publication of the *Framework* in 2012, little guidance has been produced to support curriculum designers and teachers in this work, especially when the focus is on phenomena that is contemporary, relevant, authentic, and computationally rich.

Computational and Systems Thinking in the Science Classroom

As our society becomes more technologically advanced, our workforce shifts toward a knowledge economy, and scientific fields become more interdisciplinary and computational, it is becoming increasingly important for K-12 students to develop a foundation of computational practices. The Computational Science Project investigated how to design and enact high school science curriculum materials that were computationally-rich. The STEM + Computing (STEM+C) program at the National Science Foundation specifically provides funding for the development of innovative approaches focused on infusing computing into STEM teaching and learning. Moreover, supporting students develop computational practices is an equity strategy that helps prepare all students for an increasingly computational workforce.

Computational inquiry, or “using mathematical and computational thinking”, is explicitly identified as one of the NGSS scientific and engineering practices, but with little clarification about what specifically constitutes computational thinking in a science classroom (NGSS Lead States, 2013). This stems from the fact that the research community has not yet come to consensus on a definition of computational thinking or inquiry or what it means for science learners. For example, multiple workshop reports from the National Research Council have explored the scope, nature, and pedagogical aspects of computational thinking, however these workshops were not intended to result in a consensus among the committee members and instead explored diverse perspectives (National Research Council, 2010; 2011).

In this absence of a consensus from researchers and guidance from the standards, it was important for the members of the CSP's design team to develop an understanding of how computational thinking practices and tools could be employed to help students engage in sensemaking of scientific phenomena, and in particular, investigations of large, complex scientific phenomena, such as climate change and evolution. The Computational Science Project (CSP) was focused on three epistemic scientific practices from the *Framework* (National Research Council, 2012): developing and using models, analyzing and interpreting data, and using mathematics and computational thinking. In addition, the project's computational thinking (CT) framework was further refined by bringing in the practices of systems thinking. Similarly, Weintrop and his colleagues (2016) described computational inquiry practices as including *data practices* (e.g., collecting, creating, and analyzing data), *modeling and simulation practices* (e.g., using and building computational models), *computational problem solving practices* (e.g., programming) and *systems thinking* (e.g., investigating complex systems, understanding relationships within a system, thinking in levels) (Weintrop et al., 2016).

The epistemic practice of systems thinking was integrated into the CSP's CT framework, in service of the goal of engaging students in the study of real-world complex systems phenomena (Jacobson & Wilensky, 2006; Weintrop et al., 2016; Yoon, Goh, & Park, 2017). Systems thinking is "understanding how behavior of phenomena at different scales is related and how larger scale patterns emerge from the interdependent components at lower scales" (Bar-Yam, 2016 as cited in Yoon, Goh, & Park, 2017, pg. 286). Systems thinking concepts are embedded into the crosscutting concepts of the *Framework* and *NGSS*. Engaging students in the use of computational tools to make sense of complex natural phenomena through data creates opportunities for students to engage in data practices, modeling and simulation practices, and systems thinking.

Collaborative Curriculum Design

The Computational Science Project took a collaborative approach to curriculum design within the context of a research-practice partnership. In broad terms, collaborative curriculum design, or co-design, is the process by which teams work together on the design and adaptation of educational interventions. These design communities bring together professionals—often teachers—with the mutual goal of creating a designed product in the form of a curriculum artifact (see Voogt et al., 2015). When a research-practice partnership (RPP) is focused on curriculum design, it is known as a design-RPP (Coburn, Penuel, & Geil, 2013). Design-RPPs create a design community with members that have varying types of expertise, such as researchers, practitioners, and disciplinary experts (e.g. Linn, Songer, & Eylon, 1996; O'Neill, 2016; Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013; Severance, Penuel, Sumner, & Leary, 2016). However, empirical research design-RPPs in education is sparse but growing (Coburn & Penuel, 2016) with most existing research focused on the dynamics (e.g., partnership challenges) and outcomes (e.g., designed intervention, student learning outcomes) of this partnership work. This study aims to provide a window into the processes and strategies of co-design when a team encounters a design tension, which can be thought of as a particular point in design work in which a decision about a design element must be made to move forward.

Design Tensions Framework

Through this collaborative approach to curriculum development, design tensions and alignments surface and must be navigated. As was also described in Chapter One, Tatar's (2007) design tensions paradigm presents tensions as an integral part of the design process. In this way, a design tension is operationalized as "the tension between what *is* and what *ought to be*" (p. 415), or as a choice between *this vs. that*. Tatar's (2007) design tensions framework introduces four levels of concern during the design process: vision, approach, project tensions, and "as created" situations. Project tensions—which I call *design tensions*—are described as the value-laden design decisions that occur in a project during times of conflict or moments of decision-making, such as a when "means, ways, and values come into conflict" (Tatar, 2007, p. 418). Design tensions are navigated through a process of negotiation. In the study presented in this chapter, the focus of inquiry is on a particular design tension: the process of developing and applying criteria for selecting scientific phenomena for curriculum design purposes.

It must be noted, as also explained in Chapter One, that Tatar's (2007) design tensions framework was developed within the field of human-computer interactions to understand the process of adapting mathematics educational software, and was later applied by Severance, Leary, and Johnson (2014; Johnson, Severance, Penuel, & Leary, 2016) to the field of learning sciences. Tatar's framework was adapted to provide an analytic lens of the design tensions that surfaced during the collaborative design of a digital mathematics curriculum. It is an application of Tatar's framework to employ it in this way, in which it provides an analytic lens for examining the ways that the members of a design-RPP negotiated design decisions.

Knotworking and Mycorrhizae

The members of the CSP engaged in knotworking (Engeström, 2008) as a way to negotiate the design tension of selecting scientific phenomena for curriculum design and instruction. Engeström's concept of knotworking, which is rooted in cultural-historical activity theory (Engeström 2001, 2008; Foot, 2014), is a key analytic concept for this study.

Knotworking, as shown in *Figure 6*, is a way of thinking about how temporary work groups come together (knot tied) to solve an immediate problem, and then disband (knot untied). These teams are "rapidly pulsating, distributed, and partially improvised" as they expand and contract in size and expertise, and change and morph as needed to solve a problem (Engeström, 2008, p. 194). The knot of activity is tied from "loosely connected actors and activity systems," so the knot does not hold (Engeström, 2008, p. 194). In knotworking, the threads of activity are untied and re-tied again and again in response to the changing needs of the problem and solution, in a longitudinal process that can span the trajectory of a design problem (such as a curriculum, product, or service) (Engeström, 2008). Knotworking provides a conceptual tool for understanding the fluid process of how a design team forms, changes, expands, contracts, and dissolves within the larger context of a research-practice partnership. Through knotworking, the researcher recognizes the dynamic, boundary crossing nature of collaboration.

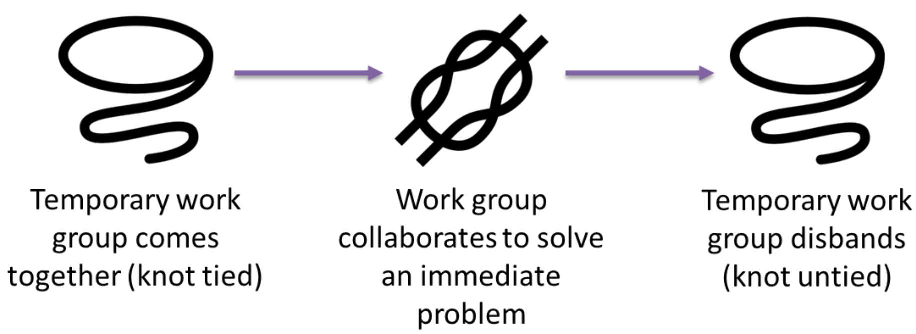

Figure 6. Engeström's (2008) concept of knotworking captures the dynamic process of the formation and dissolution of temporary work groups.

Engeström (2007, 2008) extends his metaphor of knots and knotworking by pulling in a bit of botany and mycology. Underlying this fluid process of tying and untying knots of activity with temporary work groups lies an invisible structure which Engeström likens to the subterranean, symbiotic relationship that occurs between plant roots and mycorrhizae. Mycorrhizae are the underground structures of fungi whereas mushrooms are the aboveground fruiting body of a fungus. Beneath the soil is an underground mat of tiny fungal threads which entangle and inhabit the roots of plants, at intercellular and extracellular levels depending on the species of fungus. These are usually symbiotic relationships, as shown in *Figure 7*, with the mycorrhizae aiding the roots of surrounding plants in the absorption of water and soil minerals; the plants, in turn, provide the fungus with carbohydrates created through the process of photosynthesis. In this biological collaboration, the mycorrhizae both feed and are fed by the plants.

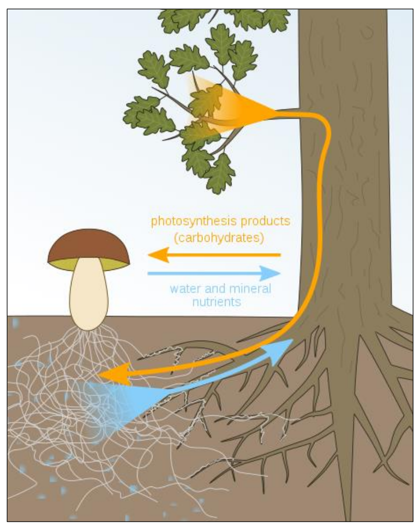

Figure 7. Symbiotic relationship between fungal mycorrhizae and plant roots. From “Mutualistic Mycorrhiza,” by Nefronus, 2019, (https://commons.wikimedia.org/wiki/File:Mutualistic_mycorrhiza_en.svg). Reprinted with CCA-Share Alike 4.0 International license.

With Engeström’s (2007, 2008) metaphor, plants represent the visible, erect, rooted, stable, yet bounded institutionalized activity systems of the partnership (i.e., school, district, non-profit organization, or university). Entwined among the plant roots is the mycorrhizae of partnership, an invisible, horizontal growing, and unbounded entanglement that connects these institutionalized activity systems through shared visions and collaborative work. These are symbiotic relationships, with the mycorrhizae of the partnership aiding the interacting activity systems by providing the stabilizing infrastructure that is needed for knotworking to occur. As Engeström describes it, “knotworking eventually requires a mycorrhizae-like formation as its medium or base” (2007, p. 11). The mycorrhizae is a living, expanding, and changing system, a “bundle of developing connections” (Engeström, 2007, p. 11). At the same time, it is also a durable and stable structure that is both cognitive and material (Engeström, 2007, 2008). These features allow for the work group, through knotworking, to expand and contract as necessary within the context of the overall partnership.

In this chapter, I present a qualitative design narrative of how the members of the Computational Science Project engaged in knotworking and other activity structures to negotiate an important design tension in their co-design work: *how to choose between many possible scientific phenomena for a curriculum unit?* The members of this design-RPP iteratively developed selection criteria for choosing scientific phenomena that was contemporary and computationally rich and then employed that criteria for the design of a NGSS-aligned high school biology unit focused on an outbreak of Sea Star Wasting Disease.

Methods

This design-based research study (The DBR Collective, 2003) employed qualitative methods (Merriam & Tisdell, 2016) to study the Computational Science Project (CSP), a research and design initiative in which interdisciplinary collaborators co-designed curricula that aimed to broaden participation in science learning with the support of computational thinking practices and tools (see Chapter One). This chapter features a design narrative (Bell, Hoadley, &

Linn, 2004) of a particular design tension that surfaced as the team sought how to select an anchoring phenomenon for a biology curriculum unit. Methodologies included ethnographic field methods (Emerson, Fretz, & Shaw, 2011), design-based research (The DBR Collective, 2003), and design narrative (Bell, Hoadley, & Linn, 2004). Design narratives, a method of design studies, are useful for understanding the challenges and successes of the evolution of an educational innovation by communicating design knowledge through the stories of the people, tools, activities, and learning contexts involved in its design (Bell, Hoadley, & Linn, 2004). This paper reports on a subset of data and findings from the larger Computational Science Project.

Study Context

In this paper, I present a narrative of the design of a project-based curriculum unit for high school biology courses focused on evolution, climate change, and computational inquiry. The six-week unit was designed for alignment with the NGSS with a focus on evolution and natural selection, using the recent Sea Star Wasting Disease (SSWD) epidemic on the West Coast of the U.S. as an anchoring phenomenon. This unit was aimed at developing students' understanding of natural selection, adaptation, extinction, and evolution of disease resistance in relation to an authentic contemporary phenomenon. The driving questions for the unit were: *What is causing changes in Sea Star Wasting Disease? How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?* and *What can we predict about the future of the species, given warming trends in sea surface temperatures?*

The Computational Science Project partnership consisted of the following partners: a research group consisting of learning scientists at a large public university; Tech Foundation[5], a STEM-focused educational non-profit organization; and a partner school and district. The partner

[5] All partner names are pseudonyms.

school, STEM Academy, was jointly managed by the district and Tech Foundation. This was a public, STEM-focused secondary school that served a community of linguistically and culturally diverse students. The school employed interdisciplinary, project-based learning approaches that emphasized social and educational justice. It should be noted that as described in Chapter One and Chapter Three, during the timeline of this study, STEM Academy merged with another neighborhood school to form Cascade STEM School. This chapter reports on curriculum design work that occurred with STEM Academy teachers up until its last year of operation and curriculum enactment that occurred during the first year of the new, merged Cascade STEM School; therefore, for simplicity I refer to the school as Cascade STEM School throughout this chapter. The CSP unfolded over three years among a shifting contextual landscape. The school merger represents one of these major shifts. It should also be noted that there were high levels of turnover at both Tech Foundation (e.g., instructional coaches, education manager), as well as STEM Academy and Cascade STEM School (e.g., teachers, principal) during the timeline of the CSP. For example, three individuals in turn held the same positon of project manager/instructional coach at Tech Foundation, representing a short tenure for each of them.

Researchers, teachers, and scientists engaged in collaborative curriculum design as part of the larger Computational Science Project. Like many other design-RPPs, we used design-based research (DBR) methodologies to guide our collaborative approach to design and research activities (The Design-Based Research Collective, 2003). This approach includes iterative cycles of design-enact-redesign and within that, micro-cycles of design work. The overall goals of the CSP partnership focused on the study of how project-based learning experiences can increase students' capabilities and interests in computational STEM pathways and to understand how computational tools and practices can broaden the scope of science inquiry in high school science classrooms for students and their teachers. The project was supported from a grant from the National Science Foundation and a research fellowship from the George Lucas Education Foundation.

Three computationally-rich curriculum units were produced by the members of the CSP: one chemistry and two biology units. The first unit designed was a chemistry unit focused on early Earth's history that integrated earth/space science with chemistry concepts and engaged students in the design of a location-based augmented reality game using the Taleblazer (MIT STEP Lab) platform. The second unit designed was the biology unit that is featured in this chapter; it focused on evolution and climate change using an outbreak of Sea Star Wasting Disease as the anchoring phenomenon. In this unit, the final project challenged students to create an infographic that presented their analysis of publicly available data sets regarding sea surface temperatures, sea star sub-population counts, allele frequency distributions in sea star sub-populations, and a causal loop model. The third unit designed was a shorter biology unit focused on infectious diseases and climate change. In this unit, the final project engaged students in data analysis regarding a case of avian influenza. See *Appendix B* for details about each of these three units.

Participants

The participants in this research study included the members of the CSP team, which consisted of five learning scientist researchers from the university, as well as partner teachers from Cascade STEM School and an instructional coach from Tech Foundation. The focal partner biology teacher from Cascade STEM School, Ms. Ly[6], was involved in co-design, adaptation, and enactment of the curriculum unit featured in this chapter. Twenty-seven of Ms. Ly's forty

[6] A pseudonym.

ninth-grade students from two class periods were also participants in this study, providing insights into student voice and experience. Three collaborating biology teachers from two districts outside of the CSP partnership also participated in this study.

Data Sources

Ethnographic field methods (Emerson, Fretz, & Shaw, 2011) were employed by multiple members of the research team to collect ethnographic field notes and develop analytical memos from work group meetings and design sessions. Artifacts were an important source of data, including collaborative project planning meeting notes, design artifacts, and project archives. The data sources and analytical approaches are presented in *Table 5*. In addition, *Table 5* provides additional details about practical measures surveys that were administered to students during the classroom enactment of the unit. Practical measures, or measurement for improvement, are surveys administered to students to capture real-time, specific data about how students are feeling about classroom activity, engagement, and interest that allow their teachers to make reflexive shifts in curriculum and instruction (Yeager, Bryk, Muhich, Hausman, & Morales, 2013).

Table 5. Data Sources and Methods of Analysis

Data Sources	Data Analysis
CSP Weekly Meetings: Notes from weekly project meetings. These notes were co-written by attendees in a cumulative Google document during weekly project meetings. *(2016: 71 pgs; 2017: 63 pgs).* **Climate Science Working Group Meetings:** Field notes, analytical memos, and documents (agenda, slide deck, working documents) from three working group meetings. *(January, February, and April 2017).* **Consulting Teacher Meetings:** Field notes, analytical memos, and design documents from two co-design sessions and classroom	**Methodology:** Design-based research Single case study Design narrative **Methods of Analysis:** Ongoing analysis and analytical memos. Retrospective content analysis with open coding for *in vivo* and *a*

enactment with two consulting biology teachers. *(April 2017).* **Project Archives:** Various sources documenting partnership formation, funding, and reporting.	*priori* concepts.
Practical Measures Surveys: Student voice was an important part of the enactment, adaptation, and revisions to the unit. Online surveys were administered to students at four time points during the unit enactment to elicit students' experiences, reflections, and suggestions for the unit. Constructs were repeated to allow for comparison over time.	**Methodology:** Survey research **Methods of Analysis:** Descriptive statistics, coding of open-ended responses, and analytic memos.

Data Analysis

Data was examined using the guidelines of a grounded theory approach (Charmaz, 2001; Merriam & Tisdell, 2016). Glaser and Strauss's grounded theory approach is a strategy for analyzing data that begins with a case or event and gradually, through an iterative process of coding, progresses to more abstract categories and themes that help "to synthesize, to explain, and to understand" the data and to "identify patterned relationships within it" (Charmaz, 2001, p. 335). Data analysis occurred through three iterative phases: ongoing, retrospective, and thematic. *Table 6* presents some of the major and minor codes from the code book. In addition, I analyzed student survey data through the use of descriptive statistics for quantitative responses (Likert-scale) and coding of open-ended responses to understand students' experience with the enacted curriculum.

Ongoing Analysis. As a design-based research project, the members of the CSP research team engaged in ongoing analysis of artifacts and field notes and the writing of in-process analytical memos (Emerson, Fretz, & Shaw, 2011; Strauss & Corbin, 2008) throughout the project to inform and shape our design work. In-process analytical memos are a way for the ethnographic researcher to "collect and analyze data simultaneously, allowing analytic concerns generated by initial observation and interviews to guide and focus the collection of new data" (Emerson, Fretz, & Shaw, 2011, p. 123). Memos were written collaboratively by the CSP researchers involved in data collection.

Retrospective Analysis with Open Coding. After identifying the relevant data sources for the research questions, I engaged in retrospective open coding (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016) through the use of content analysis (Merriam & Tisdell, 2016) of meeting notes, in-process analytical memos, design documents, artifacts, and project archives in order to reconstruct a narrative of the process of phenomenon selection that stretched over two years of the project. Open coding allows for *in vivo* codes to emerge from the data as well as for the identification of *a priori* concepts from the research literature (Emerson, Fretz, & Shaw, 2011; Merriam & Tisdell, 2016). I began by analyzing the cumulative project planning notes from the team's weekly planning meetings. Next, I examined the documents and artifacts related to meetings of an ad hoc workgroup, the Climate Science Working Group. Finally, I analyzed the documents and artifacts related to co-design and classroom enactment with consulting biology teachers. Analysis focused on identifying and articulating the processes, activity structures, and design tools and resources, as well as the affordances and challenges of selecting a phenomenon in order to reconstruct a narrative of this work. Analytical memos were developed throughout this process.

Thematic Analysis with Axial Coding. As I engaged in each round of coding, I began to group individual codes into sub-codes, which then were collapsed by theme into major code categories (see *Table 6*). This process of axial coding (Merriam & Tisdell, 2016; Strauss &

Corbin, 2008) was followed by theoretical coding (Merriam & Tisdell, 2016) in which categories were compared across multiple data sources.

Table 6. Major Code Categories and Sub-codes

Major Code Categories	Sub-Codes
Knotworking Activity Structures	Weekly project meeting Climate Science Working Group Consulting science teachers Consulting scientists Specific activity structure (i.e., small working group, brainstorm, providing feedback)
Tools & Resources	Tools (i.e., tools for curriculum design) Resources for teaching climate science Resources for teaching genetics
Phenomena Characteristics	Authentic Contemporary Controversial Unsettled/uncertainty Locally relevant
Computational Thinking	Computational thinking Computational tool Systems thinking
Potential Phenomena Identified	For Chemistry Unit #1 For Biology Unit #2 (Sea Star Wasting Disease Unit) For Biology Unit #3 (Infectious Disease Unit)
Co-design Practices	Co-writing Member checks Checking flow between units (e.g., chemistry and biology) Ensuring alignment (e.g., NGSS, district scope/sequence) Making connections with climate science Emphasis on student engagement (e.g., choice, experience) Design of PBL project Considering pedagogies for phenomenon-based instruction Grounding phenomenon in a narrative
Approaches to Design Work	Socio-scientific approach Phenomenon-based instruction

Validity. Validity strategies included triangulation across data types, sources, and perspectives (Merriam & Tisdell, 2016). I engaged other researchers on the team to check the accuracy of my interpretation and reconstruction of our work processes. I also returned to the data during the writing of this chapter in order to develop a "thick description" (Geertz, 1973 as described by Merriam & Tisdell, 2016) of unfolding activity and decision-making captured in this design narrative.

Researcher Positionality

The collaborating team that made up the CSP partnership included partner teachers from STEM Academy and Cascade STEM School, a project manager/instructional coach from Tech Foundation, and the university research team. The CSP researchers included: a professor of learning sciences who directed the project as the Principal Investigator; a post-doctoral researcher with a background as a science teacher and ecologist; a graduate researcher who was formerly an evolutionary biologist; a graduate researcher with a background as a science teacher and a marine biologist; and myself, a graduate researcher with expertise in curriculum design. All members of the research team were trained as learning scientists. My overall role in the CSP was as a researcher and curriculum designer. I brought to this role almost two decades of experience in designing science education curriculum materials as a consultant and experience managing science education programs. As part of the CSP, I took on the role of an active participant in weekly planning meetings and contributed to our collaborative meeting notes. While my colleagues on the research team acted as participant-observers (Merriam & Tisdell, 2016; Gay, Mills, & Airasian, 2012) during meetings with the consulting biology teachers and members of the Climate Science Working Group, I was not present for most of these events; therefore data analysis was centered on the artifacts generated before, during, and after these events rather than my personal experience as a participant in these events. I was involved in the design of the templates used for curriculum design work, and once the biology unit was authored and piloted in Ms. Ly's classroom, I took the lead on implementing revisions to the curriculum and preparing it for publication and dissemination, however I was not the lead author on the curriculum unit. During the initial enactment of the unit, I collected data through classroom observations while also meeting with Ms. Ly for instructional debrief sessions several times a week and helping to support her enactment of the curriculum. I approached this study as a learning scientists with expertise in curriculum design for science and engineering education.

Findings

In this chapter, findings center on the perspectives of members of the design-RPP who engaged in the design of a three-dimensional, phenomenon-based curriculum unit for high school biology. I present our iterative process for selecting SSWD as the unit's anchoring phenomenon as it unfolded and describe its particular features. To communicate the narrative of this work, these processes have been organized into three phases, recognizing that in practice the process was iterative and reflexive. In Phase One, we focused on developing our general criteria while at the same time engaging in launching the partnership and designing a chemistry unit. I present our organizing principles, constraints, and partners' influences at the project-level, which sharpened our focus on particular priorities for phenomenon selection and curriculum design. In Phase Two, we developed the specific criteria that would be used for two biology units and selected the anchoring phenomenon for the biology unit featured in this chapter. I share the criteria that we collaboratively developed for phenomenon selection, grounded both in research literature and the NGSS. I then describe knotworking and other activity structures that occurred within the partnership through the process of selecting the phenomenon. In Phase Three, we engaged in the collaborative design, enactment, and revision of the biology unit. I summarize our process of expanding upon the chosen anchoring phenomenon to design investigative, project, and assessment phenomena for the curriculum unit. It is also important to understand students' experiences with the phenomenon during its enactment in their biology classes. Therefore, I also highlight several findings from data that purposefully elevate student voice.

The goal at the beginning of the Computational Science Project was to develop curriculum units focused on earth/space science and climate science since those fit the interests of collaborating teachers and the goals of the CSP. There was some uncertainty at first if we would develop the units for middle school or high school courses, and if we would develop units for chemistry or biology classes, due to a shifting landscape at the district and school level in regard to scope and sequence, courses, teacher turnover, and teaching assignments. We eventually settled on developing three high school units: a) a chemistry unit focused on early Earth's history; b) a biology unit focused on climate science and evolution; and c) a biology mini-unit focused on climate science and infectious diseases. All were designed as PBL units with a strong focus on computational thinking practices that also integrated earth and space sciences content. In this chapter, I focus only on the climate science/evolution unit developed for high school biology courses with some references to relevant design activities that occurred across all three units.

It was during the design of the two biology units that the design team struggled with selecting an anchoring phenomenon for each unit that met our criteria for selection. As will be described, several ad-hoc groups were formed and dissolved during this phase to bring people with different forms of relevant, deep expertise to the design table and the selection process. This included: a Climate Science Working Group; a series of design teams in which researchers collaborated with two experienced biology teachers from a district outside of the partnership, Ms. Ly our partner biology teacher, and then a third consulting biology teacher from a different district outside of the partnership; and consultations with disciplinary experts. This phenomenon of an ongoing Sea Star Wasting Disease epidemic was surfaced during two of the three meetings of the Climate Science Working Group, but the design team turned its focus first to extreme weather and ocean acidification, and later to tetrapod evolution in partnership with two consulting teachers. However, each of these phenomena were judged to not meet our full set of selection criteria. Many potential phenomena were then explored, researched, and pitched, with the research team eventually selecting the West Coast epidemic of Sea Star Wasting Disease as the anchoring phenomenon for the evolution/climate change unit featured in this chapter. Initial unit design was led by two learning scientist graduate students (Klein and McGowan) with backgrounds in evolutionary biology and marine biology, followed by a co-design practice between the researchers and Ms. Ly who provided feedback and engaged in local adaptation during the enactment of the unit in her classroom. Supports were provided during unit enactment, including co-planning, co-teaching, instructional debriefings, and involvement of scientists (see Chapters Three and Four).

Figure 8 highlights the activity structures and instance of knotworking that occurred across all phases that will be unpacked in the following sections. During these phases of phenomena selection and unit design, it is important to note that the research team was simultaneously engaged in the process of developing a template system for the design of NGSS-aligned, phenomenon-based, PBL curriculum units. The template system is embedded with tools for design work, such as unpacking performance expectations, developing driving questions, identifying investigative phenomena, and creating three-dimensional summative assessments. The template system was developed through and informed by our experience of designing the units.

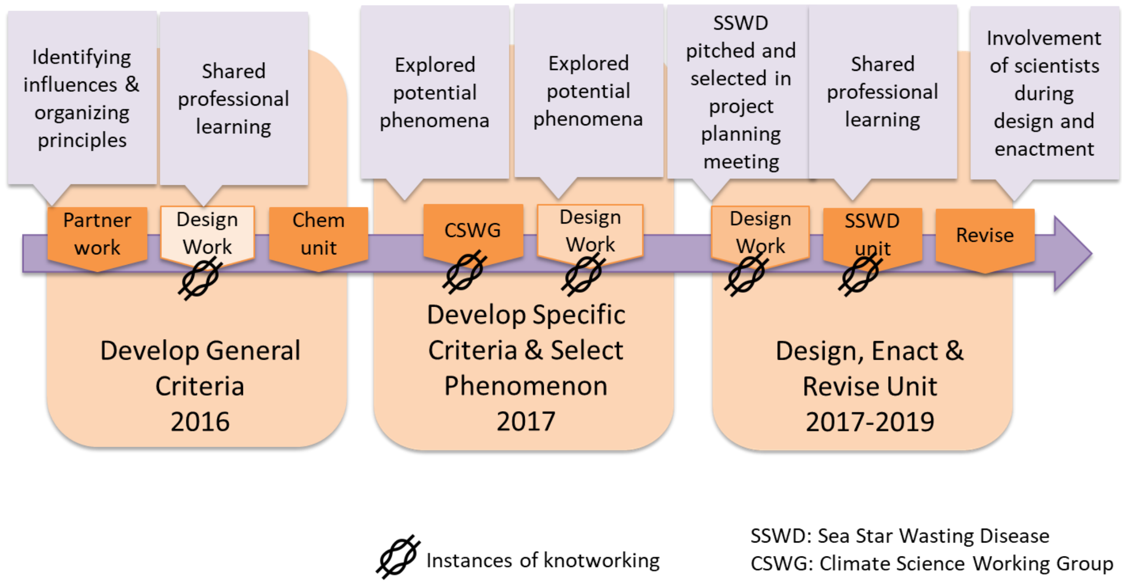

Figure 8. Activity structures and knotworking across three years of a design-RPP focused on the selection of phenomena for a NGSS-aligned biology unit.

Phase One: Developing General Selection Criteria

I begin by retelling the narrative arc of our process of developing and applying selection criteria across the three phases of collaborative work. The process of phenomenon selection began with developing general criteria for selecting phenomena for the three curriculum units. This process occurred during the initial phase of the project, alongside the early work of establishing the partnership, identifying influences, constraints, and priorities, developing our design practices, and designing the first of three curricula—a chemistry unit focused on early Earth's history. *Figure 9* captures some of the activity structures involved in this initial phase of work.

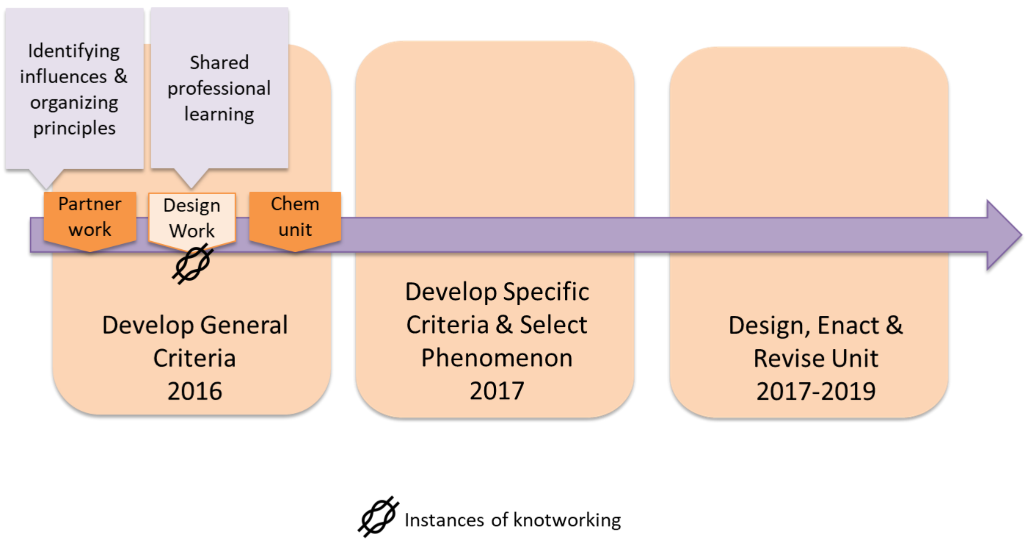

Figure 9. Activity structures across the first phase of developing a general criteria for phenomenon selection.

Organizing principles and influences. As we engaged in partnership building, it was important that we begin to understand the priorities, interests, and areas of expertise of the members that made up the CSP. *Figure 10* depicts some of these organizing principles and influences. As a research-practice partnership, our design choices were informed by the design principles for the Computational Science Project as a whole, as well as by the contexts of our partner school and district. School and district policies, infrastructure, curriculum scope and sequence, and areas of focus also informed our development of criteria for selecting scientific phenomena for curriculum design. For example, the district was in the midst of adopting NGSS-aligned science curriculum and was integrating earth and space science content across its existing life and physical science courses. Our partner school, STEM Academy that later became Cascade STEM School, served youth of color and youth from low-income families with a STEM education focused on students' academic, social, and emotional needs, with an emphasis on building bridges to college and careers. The mission of the school emphasized five pillars: a social justice and equity focus; an interdisciplinary approach to project-based learning (inspired by the Buck Institute model of PBL) in which class projects build toward exhibitions throughout the year; STEM and humanities integration, in which PBL projects emphasize connections between science and humanities; college and career readiness focus; and developing students' capacity as digital citizens ready for 21st century workplaces through the use of educational technologies. Teachers at the school emphasized the importance of student interest and choice when designing instruction. Additionally, we considered the geographic setting of the school, with its location in a community along the Puget Sound, an inland sea along the West Coast of the United States.

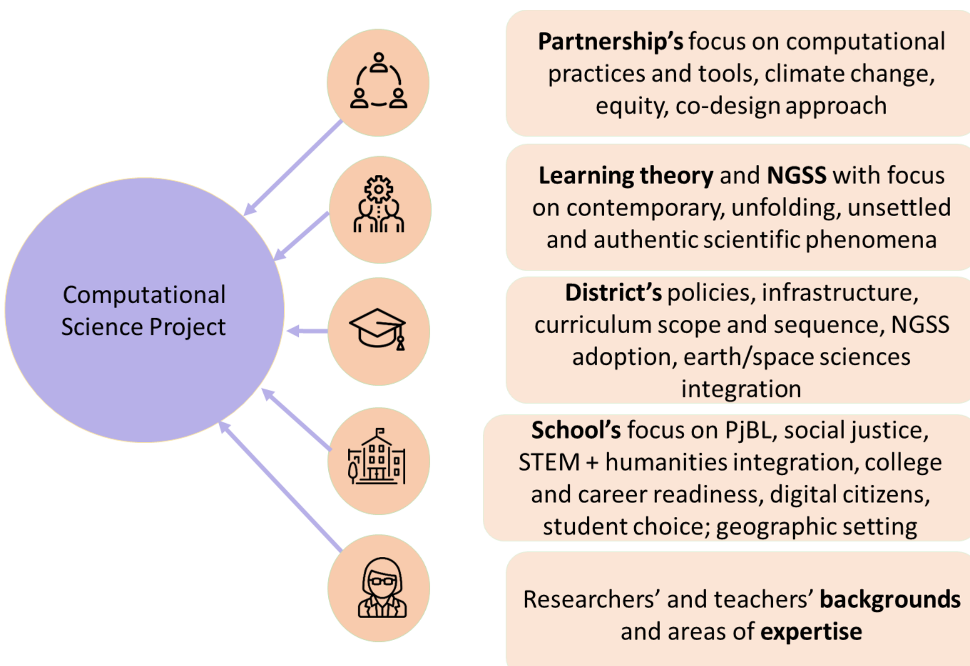

Figure 10. Organizing Principles and Influences of the Computational Science Project.

In particular, the following organizing principles guided our co-design work and provided the context for which we ultimately selected the West Coast epidemic of Sea Star Wasting

Disease as the anchoring phenomenon for the biology unit focused on climate change and evolution. These organizing principles captured the partnership's priorities and goals:

- Grounded by a social justice and equity lens (Bang et al., 2013; Bell, Tzou, Bricker, & Baines, 2012; National Research Council, 2012).
- Recognized the importance of student interest (Bricker & Bell, 2014), everyday expertise (Bell, Bricker, Reeve, Zimmerman, & Tzou, 2012; Zimmerman & Bell, 2012), and disciplinary identity (Bell, Tzou, Bricker, & Baines, 2012; Bell, Van Horne, & Huagan Cheng, 2017; Bricker & Bell, 2012; Nasir & Hand, 2008; Van Horne & Bell, 2017).
- Chose the pedagogical approach of NGSS-aligned, phenomenon-based instruction (National Research Council, 2012; NGSS Lead States, 2013).
- Incorporated unsettled, unfolding scientific phenomenon (Bell, 2004; Manz, 2018; Manz & Suárez, 2018).
- Viewed climate change as a contemporary science issue (Bell, 2004).
- Recognized climate change and evolution as socio-scientific issues (Bell, 2004; Morrison, Bell, Chowning, & Klein, 2017; Van Horne & Bell, 2014).
- Placed an emphasis on the integration of computational practices and tools into the science classroom (Weintrop et al., 2016).
- Chose the design approach of collaboration with supporting activity structures (Bergsman, McGowan, Klein, Morrison, & Bell, 2019).

In addition to these partnership level influences, the researchers' and partner teachers' expertise and background also mattered, further constraining and funneling us toward the development of selection criteria and ultimately our selection of scientific phenomena to anchor the two biology units.

Shared professional learning. In this initial phase of the project, we engaged in shared professional learning at research group meetings. These learning activities included shared readings, the collaborative development of an annotated bibliography, exploration of existing curriculum resources, conversations with each other, and consultations with experts. Through this practice of shared learning, we developed our common knowledge of climate change education, computational thinking frameworks and tools, relevant NGSS standards, resources for phenomenon selection, and approaches to designing three-dimensional summative assessments. For example, we leveraged resources from within our research group, as well as external resources to develop our shared understand around phenomena selection. We also sought to understand curriculum design practices that would help with selecting our anchoring phenomenon, such as standards bundling and storylining (Storylines Team, n.d.).

Flexibility with shifting priorities. With many layers of priorities and interests among CSP partners, flexibility became an important quality. Early in this process, we thought that the first unit we would design would be focused on climate change. During one of these early design sessions, the attendees collaboratively created a causal loop diagram for the phenomenon of climate change (see *Appendix H*). However, due to the shifting landscape of school and district priorities, our attention was instead turned toward developing a chemistry unit focused on early Earth's history—since chemistry became the teaching assignment of the two lead collaborating teachers. We would later return to the phenomenon of climate change for the development of two biology units.

Knotworking for initial design work. During Phase One, we took a co-design approach to curriculum development by convening a design team that involved science teachers (including two key teacher-designers), educational researchers, and at times, disciplinary experts with relevant background in chemistry. We engaged in knotworking (Engeström, 2008) as the design team formed, met for a series of thirteen in-person design sessions to develop the chemistry curriculum, and ultimately disbanded. The design team used a storylining approach (Storylines Team, n.d.) to curriculum design, using collaborative online software (e.g., Google Sheets, Google Docs) to design together.

Phase Two: Developing Specific Selection Criteria

The project-level design principles created the context from which we developed our criteria for phenomenon-selection. These criteria are instantiations of our theoretical framework, the project's design principles, our co-design practices, and activity structures. The process of developing this criteria was iterative. We engaged in knotworking (Engeström, 2008) through the convening and dissolving of ad hoc working groups that brought together diverse forms of expertise when it was needed; this will be described in detail in this section. These stories of knotworking in Phase Two included bringing together people with diverse cross-disciplinary expertise through the Climate Science Working Group and bringing together people of specific curriculum design and pedagogical expertise through a temporary collaboration with two biology teachers. See *Figure 11* for an overview of this phase of work.

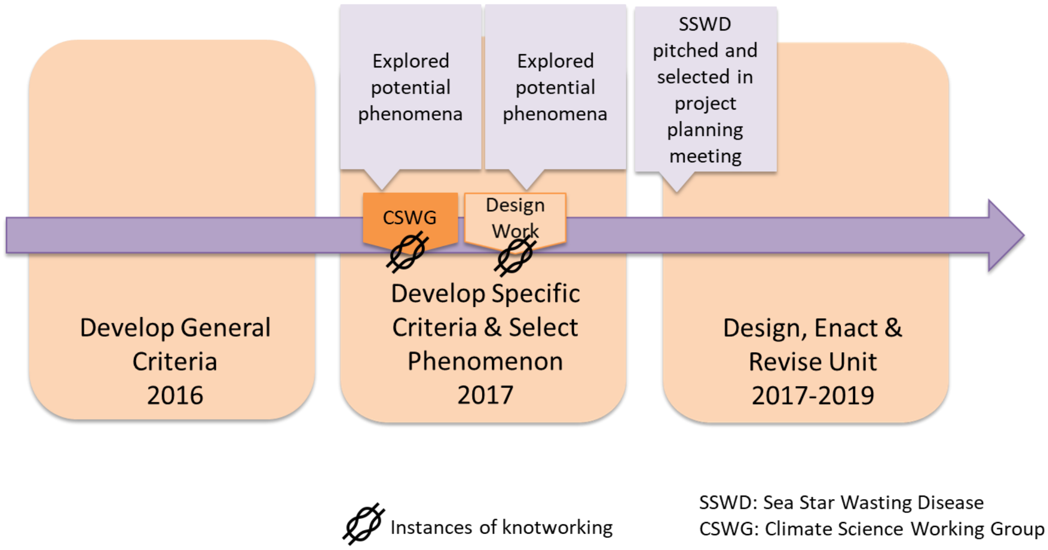

Figure 11. Activity structures across the second phase of developing a specific criteria and selecting the anchoring phenomenon.

Selection criteria for anchoring phenomenon. First, I present the CSP's selection criteria for anchoring phenomena for a computationally-rich biology unit focused on climate change and evolution. I will then share a detailed narrative of how the members of the CSP developed and utilized these criteria, with a specific focus on activity structures, including knotworking. Our criteria for choosing our unit's driving phenomenon are divided into three categories: theoretical, computational thinking, and design criteria, as presented in *Table 7*. In addition, a fourth criterion emerged during the enactment of the unit. Though this set of selection criteria is specific to the priorities and goals of the Computational Science Project, it may be of value to others engaged in the design of phenomenon-based science curricula.

Table 7. Selection Criteria for Anchoring Phenomena for a Computationally Rich Biology Unit Focused on Climate Change and Evolution

	Criterion	Description
Theoretical Criteria *Guided by learning theory*	Is it local and relevant?	Phenomenon is locally-occurring, interesting, and relevant to students' lives.
	Is it authentic and contemporary?	Phenomenon presents a real-world, contemporary scientific problem that is unsettled, unfolding, and currently under study by scientists across disciplines.
Computational Thinking Criteria *Guided by the NRC Framework, the NGSS, and the project's computational thinking framework*	Does it exist within a complex natural system?	Phenomenon occurs within a complex natural system and benefits from a systems thinking approach.
	Are there publicly available data sets and computational tools?	Data--collected by both professional and citizen scientists--is publicly available; the type and format of data allows for analysis through readily-accessible computational tools. In addition, scientists studying the phenomenon are remotely available to support curriculum designers, teachers, and students.
	Are there existing computational simulations and models?	Disciplinary content (e.g., climate change, evolution, natural selection, allele frequency, phylogenetic trees) can be connected to existing simulations and models, including those that are computational in nature.
	Are there strong connections to biology and earth/space sciences content?	The phenomenon presents opportunities for students to engage in scientific and computational practices while learning core content in biology (e.g., evolution and natural selection) and earth and space sciences (e.g. global climate change).
Design Criteria	Is the phenomenon large and complex?	The phenomenon is amply large and complex in order to anchor a unit of instruction and to allow for extended learning over 4-6 weeks. The anchoring phenomenon can be divided into smaller-scale investigative phenomena that help develop students' understanding of the anchoring phenomenon.

Guided by instructional goals, approaches, and constraints	Is it connected to climate change?	The phenomenon is impacted by global climate change, as an example of a complex natural system.
	Is there a project connection?	Using a project-based learning approach, the anchoring phenomenon can be used to develop a project that can span the unit.
Emergent Criteria *Guided by student experiences during the enactment of the unit*	Does the phenomenon provide an opportunity for the development of empathy for more-than-human organisms?	The phenomenon features an organism in a way that the learning activities engage students in developing an understanding of the organism's life cycle, physiology, habitat, as well as human and environmental impacts on its health and well-being.

These selection criteria were developed in an iterative process that involved a variety of activity structures, including seeking out people with specific and diverse forms of expertise who could help inform this process. As part of our approach to co-design, our design team was dynamic, expanding and contracting over time as we formed and dissolved several ad-hoc groups through the process of knotworking. These groups were intended to bring together needed forms of expertise throughout the curriculum design process.

Knotworking for diverse cross-disciplinary expertise. Through a process of knotworking (Engeström, 2008), the CSP team formed an ad-hoc working group of professionals with diverse expertise. A Climate Science Working Group (CSWG) consisting of science teachers, climate scientists, climate science educators, and learning scientists was convened in January-April 2017 over three evening brainstorming and design sessions. While attendance varied over the three meetings, the CSWG consisted of 28 participants total: eight K-12 teachers or staff from three public schools; eight university science faculty or graduate students; seven university educational researchers or graduate students; four university education faculty members; and one external evaluator. Three different universities were represented by the group. In *Figure 12*, each colored dot represents an individual who attended at least one CSWG meeting, with color coding indicating from which institution the person originated. University participants included members of the CSP research team, as indicated by outlined dots, as well as other educational researchers and disciplinary scientists (faculty and graduate students) from the same university. Individuals from external institutions included teachers from schools outside of the CSP partnership, science and education faculty from two other universities, and an external program evaluator. Individuals who were considered to be persistent actors in the CSP partnership are indicated by an outlined dot, whereas those who were engaged temporarily are indicated by a dot without an outline. The placement or clustering of the dots horizontally does not hold any specific meaning.

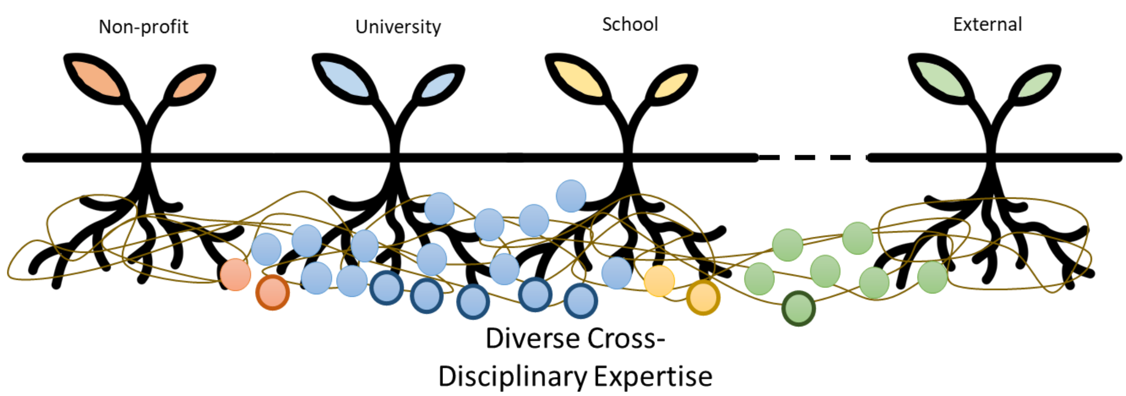

Figure 12. Knotworking for diverse cross-disciplinary expertise from the underlying mycorrhizae of the partnership through a climate science-focused working group.

The CSWG was convened in order to serve the goals of the larger project, as a way of providing a landscape analysis of climate science and climate science education, and as both a source of and a sounding board for curriculum ideas for the unit. Additionally, the CSWG was part of a broader initiative of the university team to support teacher professional development, curriculum design, and student events focused on climate science education related to NGSS. One of the major goals of the CSWG was to "inform development of new climate change curriculum units involving computational thinking and inquiry." The first meeting focused on identifying diverse expertise and areas of interest among the group meetings. The second meeting focused on crowd-sourcing frameworks and resources for computational thinking and climate science education. The final meeting focused on equitable pedagogical approaches to climate science education. Across meetings, participants met in small break-out groups for focused work related to curriculum design.

The activity structures in the three CSWG meetings served to foster collaboration, leverage the diversity of expertise in the room, and focus the participants on the work at hand. These activity structures included:

- Sharing a meal and engaging in conversation focused by "talking points".
- Eliciting the participants' areas of expertise.
- Generating posts about climate science education pedagogies and resources for use on the Twitter social media platform.
- Reviewing and providing feedback on drafts of practice briefs related to climate science education.
- Collaborating in small, topic-focused break-out groups to identify relevant NGSS Performance Expectations and recommend related scientific phenomena and engineering problems of interest.
- Reviewing and providing feedback on ideas for curriculum modules.

While many ideas for climate science-related scientific phenomena were proposed during these meetings, one particularly salient thread can be tracked across the first two meetings of the CSWG. This thread is woven across the meetings as an idea is formulated, developed, and expanded upon by a small working group.

First Meeting of the CSWG. In the first meeting of the CSWG, four small break-out groups met, each focused on a different topic that had been generated by the larger group: oceanography, atmospheric sciences, ecology/earth sciences/human impacts, and biology/economics/human health/ecosystems. Each break-out group included at least one member of the research team, allowing the researchers the opportunity to both float ideas for phenomena that had already been surfaced within the project, and to listen to new ideas proposed by the break-out group members. As the break-out group that chose to focus on the topics of "biology/economics/human health/ecosystems" brainstormed phenomena of interest, the following topics were all surfaced: climate change impacts on particular species, Sea Star Wasting Disease, evolution, adaptation, epigenetics, and infectious diseases. These topics are all aligned to our eventual selection of the anchoring phenomena for the two biology units: Sea Star Wasting Disease and infectious diseases. The diverse expertise represented by the participants in the CSWG together with in-depth brainstorming sessions on specific topics allowed for a range of potential scientific phenomena to be identified, including what was ultimately, though not immediately, selected by the CSP design team.

Second Meeting of the CSWG. In the second meeting of the CSWG, the same break-out group narrowed their focus to "epigenetics and biological connections". This group surfaced a list of potential phenomena of interest, some of which were later incorporated into the design of the two biology units. Below is a direct excerpt of researcher notes from this break-out group.

This design artifact captures the potential driving questions developed by these members of the CSWG.

Epigenetics and Biological Connections to Climate Science

Phenomena and Related Engaging Topics and Investigations

- How might anthropogenic climate change impact selection and adaptation processes for particular species? (via epigenetic factors in plant communities, disease factors such as Sea Star Wasting Disease or Zika virus, or impacts on species via range restrictions)
- What are the connections between immunity/disease resistance and changes in the earth's climate?
- Climate change as causing selection pressures on organisms, potentially leading to speciation / evolution over time. Way to show that evolution is still happening, especially in the face of climate change.
- Addressing the idea of genetic diversity + random mutations as the fodder that evolutionary processes can work on (i.e., natural selection in the face of quickly changing climate). Connect to heredity + alleles Punnett squares. → drought tolerant GMO's. **How genetics offers potential solutions to changing climate?**
- Rates of evolutionary change based on generation time (e.g., bacteria vs turtles).
- LS2-3: Dead zones in the Pacific. Anaerobic bacteria thriving; bad for fish.
- Climate science usually approached in Biology through carbon cycling lens. Climate change as "punchline" for understanding carbon cycling.

[Design Artifact from Break-out Group, CSWG Meeting; bold and punctuation retained from original]

Interestingly, Sea Star Wasting Disease was not selected by the members of the CSWG, rather, three other phenomena were selected for further development. However, many of the ideas folded into this list of potential driving questions could ultimately be identified within the biology unit that was later developed.

Third Meeting of the CSWG. At the third meeting of the CSWG the participants provided feedback on sketches of three potential curriculum units: severe weather data analysis, extreme weather modeling, and engineering solutions for ocean acidification. However, these phenomena were later judged to not fit the full design criteria due to critical feedback from disciplinary experts, as detailed below.

Scientists' feedback during CSWG meetings. One feature of our design work was engaging with disciplinary experts at the beginning of the curriculum design process, through the CSWG meetings. Scientists' involvement in these meetings was important both for helping elicit suggestions for anchoring phenomena related to contemporary scientific research and for providing critical feedback on phenomena currently under consideration. During the third meeting of the CSWG, the research team presented for the group's review three ideas for anchoring phenomena that had surfaced during previous working group meetings and had been chosen for further development. However, conversations with three disciplinary experts (two scientists and one climate science education professor) identified elements of these phenomena that were not in alignment with our selection criteria. The two excerpts below, taken directly from a researcher's analytical memo, demonstrate the importance of engaging disciplinary experts in the phenomenon selection process.

> **Developing Engineered Solutions for Ocean Acidification:** I talked with [an oceanography professor] about the ocean acidification one-pager...**he noted that ocean acidification can be neither reversed nor mitigated because of the nature of marine carbon cycles and chemistry.** He instead suggested that the engineering/ project piece be focused on reducing atmospheric carbon emissions to reduce the absorption of carbon by the ocean.
>
> **Exploring the Phenomenon of Extreme Weather Events:** Later, I talked with [a graduate student in chemical oceanography] about the modeling mini-unit. He had fantastic feedback that mirrored some of what [a climate science education professor] shared in our morning meeting. **Basically, there are no clear causal relationships between specific weather events, and changes in global climate variables, ergo, it is not possible to build a causal-loop model around this anchoring phenomena.** ...**the phenomena isn't suited for the learning goals of the lessons.** In conversation with [the oceanography student], we decided that the carbon cycle would be a better topic for the unit.

[Researcher Analytical Memo; bold retained from original]

These disciplinary experts were especially concerned with identifying a scientific phenomenon that had causal, not correlational, links to climate change. Given the socio-scientific nature of climate change, they stressed the importance of highlighting phenomenon with strong causal links and supporting evidence. These critical conversations during the CSWG meeting changed the focus on phenomenon selection away from these two proposed phenomena, sending the research team back to the drawing board as they continued to sharpen their focus.

Through knotworking, the CSP research team was able to identify needed forms of expertise and bring it together through the formation of the ad-hoc CSWG (knot tied). The activity structures of the CSWG leveraged that expertise to expand their conceptions of climate science education, to identify and evaluate potential scientific phenomena, and to pivot and negotiate design decisions in partnerships with disciplinary experts. The ad-hoc group was then disbanded (knot untied) as the CSP team moved onto to the next phase of the project: phenomenon selection and curriculum design.

Coming out of these CSWG meetings, the CSP research team continued to explore potential phenomenon for biology curriculum units focused on climate change and evolution. The team focused on how the changing climate is impacting selection and adaptation processes for terrestrial and aquatic organisms via epigenetic factors, disease factors, and restrictions on geographical ranges. This focus on climate change and speciation led the research team to explore a variety of relevant topics and phenomena—including Zika virus, Sea Star Wasting Disease (again), phenology, tetrapod evolution—and a variety of focal animals—including salmon, sea stars, coral, cyanobacterium, pika, butterflies, and North American birds—as well as food crops. As the team began exploring these potential phenomena, they continually compared each candidate against the criteria for selection, as well as asking questions, such as: how does this connect to the content and bundle of standards for a Genetics or Evolution unit?; are there relevant publicly available data sets?; what computational tools are available to compile, analyze, or visualize this data?; and how would this phenomenon work locally and in other parts of the country as a curriculum topic? One way the research team developed and tested these ideas was through partnerships with biology teachers.

Knotworking for specific curriculum design and pedagogical expertise. Another form of knotworking present in Phase Two was to engage teacher partners in collaborative curriculum design. Members of the CSP research team coordinated co-design activities with two consulting biology teachers from a district outside of the partnership, and later focused on unit design and enactment in collaboration with a key co-design collaborator, Ms. Ly[7], the biology teacher from Cascade STEM School.

CSP researchers developed a partnership with two public high school biology teachers—both of whom had participated in the CSWG meetings—to co-design prototypes of curriculum materials and test these materials in their classrooms as part of their existing genetics units. Other than participating in the CSWG meetings, these teachers were external to the CSP and were from a school district other than our partner district, providing a different perspective on the work. They were also experienced biology teachers with expertise in teaching evolution at the high school level. These two teachers met with CSP researchers for two in-person design sessions in April 2017.

[7] A pseudonym.

At the first design meeting, members of the research team shared some of the organizing principles, influences, and constraints of the Computational Science Project, including the co-design approach to curriculum development, the focus on integrating computational practices into science curriculum materials, and the importance of designing for student voice. The two consulting teachers discussed their instructional goals and timelines for their own evolution units with their biology courses. Through a design process that included the use of whiteboard brainstorming (*Appendix I*), notetaking in Google docs, and the use of a rainbow storylining tool (adapted by Bell from the NGSS Storylines project; see *Appendix J*), the teachers chose the anchoring phenomenon of tetrapod evolution. The unit-level driving questions they developed were: *How have environmental factors impacted the evolution of species in the past?* and *How will climate change impact the future of species' evolutionary trajectories?* This phenomenon had been discussed at a CSWG meeting as a potential phenomenon for curriculum design. These teachers also felt that this phenomenon was a good fit with their existing genetics units and would allow them to leverage some existing materials on whale and hominid evolution, with which they were already familiar.

The major product of this collaborative work was to develop a project that would function as a three-dimensional summative assessment for the biology teachers' genetics units. This assessment challenged student teams to choose a focal species and then develop a conceptual model to explain how environmental factors have impacted the species' evolutionary history in the past and to predict how climate change will impact the evolution of this species going forward. In the designed assessment, students could choose between these species: salmon (*Oncorhynchus spp.*), tawny owls (*Strix aluco*), European great tit songbirds (*Parus Major),* and thyme plants (*Thymus vulgaris*). These species were selected due to their connection to natural selection and climate change and the presence of variable phenotypes (i.e., body size, feather color, egg laying time, and leaf oil production). For example, salmon in the Pacific Northwest are affected by climate change impacts, including decreased levels of precipitation, warmer temperatures, and decreased water levels and flow in rivers. The body size of salmon has been shown to be genetically controlled.

The curriculum materials designed through this work served those teachers' instructional purposes but ultimately did not serve the Computational Science Project's larger purposes or fully meet the specific criteria for phenomenon-selection. For example, the computational tool, SageModeler (Concord Consortium & CREATE for STEM Institute) that the teachers chose for modeling natural selection did not ultimately meet our needs because, as captured in a researcher memo, it did not at the time have functionality for accurately modeling reproduction across generations, however it could be useful for modeling food webs and other dynamics within ecological systems. A researcher's memo following the second design session with these teachers reflected on a tension of how much was "enough" for the unit to be considered computationally-rich. She reflected:

> Although the unit ultimately incorporates some of the more general computational thinking skills (abstraction, modeling, etc.), it does not currently overtly involve practices of computational inquiry (data analysis, computational modeling, etc.) that we have been discussing on the [university] team side…They also asked me a few different times at the end of our meeting if there was 'enough' computational thinking involved. [Researcher Memo; minor punctuation correction made without changing original meaning of excerpt].

The two collaborating biology teachers enacted their designed curriculum materials with their students. While students reported on practical measures surveys that the evolution unit overall was personally-relevant, the researchers felt that the specific phenomenon of tetrapod evolution was too broad and not locally-relevant. In addition, the assessment that the teachers developed did not have a computational component; therefore it did not meet the project's larger goals.

As an example of knotworking (Engeström, 2008), this collaboration came together to extend the work of the CSWG by leveraging the expertise of two experienced biology teachers to develop and test specific ideas related to curriculum design (knot tied). However, the center of the knot did not hold. Lacking the support of their district to continue in this collaborative work and with the surfacing of design tensions regarding the vision for these curriculum materials, the collaboration ended after the teachers' enactment of their designed instructional materials (knot untied). This short-term collaboration afforded opportunities to expand upon and test out potential ideas for anchoring phenomena, computational tools, and assessment structures, as well as tools and routines for eliciting and reflecting upon student voice. These threads of design knowledge would later be taken up and woven into the work of crafting the biology unit investigating an outbreak of Sea Star Wasting Disease.

Selecting the anchoring phenomenon. After wrapping up their work with the two consulting biology teachers in Spring 2017, two members of the research team (Klein and McGowan)—both with backgrounds as biologists—continued to grapple with choosing the anchoring phenomenon for the unit that would meet our selection criteria. Various other potential phenomena—including those that had been surfaced at CSWG meetings—were explored, researched, pitched, and evaluated at weekly project planning meeting. In June 2017 during one of these planning meeting, they pitched Sea Star Wasting Disease as the anchoring phenomenon for the biology unit that would be focused on evolution and climate change. At this point, the idea of SSWD had percolated to the surface several times through our iterative process of phenomenon selection, including during the meetings of the CSWG. The pitch for SSWD included a description of the anchoring phenomenon, a potential unit-level driving question, bundling of relevant NGSS Performance Expectations, an overview of the student project, identification of relevant publicly available data sources, and suggestions of computational tools for data analysis and modeling. After discussion and consideration of the selection criteria, the research team chose SSWD as the anchoring phenomenon for the unit. Once the anchoring phenomenon was selected, the CSP team moved onto the third phase of designing and enacting the biology unit.

A West Coast Epidemic of Sea Star Wasting Disease

The research team ultimately chose the epidemic of SSWD that began in 2013 along the west coast of North America as the unit's anchoring phenomenon. The goal was then to design a unit that would extend for six-to-eight weeks, with investigations and project work that would build students' understanding of the phenomenon through deep engagement with scientific and computational practices. The instructional sequence of the unit was to support students as they investigated the unit-level driving question: *what is causing changes in Sea Star Wasting Disease?*

This phenomenon met our theoretical, computational, and design criteria for phenomenon selection for three-dimensional science instruction in high school biology classrooms. Our *theoretical criteria*, which were informed by learning theory, ask if the phenomenon is local and relevant, as well if it is authentic and contemporary. Since SSWD was an unfolding, unsettled contemporary scientific phenomenon, the unit would afford an opportunity for students to engage in uncertainty within scientific fields. Representing the largest recorded disease-related marine mortality event happening in their own georegion, we also felt that students would find the topic to be locally and personally relevant. There was a gross, cannot-look-away element to the disease mechanism that was likely to capture students' attention; media coverage of the puzzling epidemic depicted zombie starfish with melting and oozing arms. Some students living in the Pacific Northwest were also likely to attach cultural significance to sea stars and the impacts of the disease on marine ecosystems. Moreover, the scale and significance of the disease outbreak was alarming. Purple sea stars are considered to be a keystone species in intertidal and subtidal ecosystems. With some geographic sub-populations experiencing up to 100% mortality during the outbreak, scientists were concerned that the decimation to these sea star populations could lead to increased numbers of urchins, which are a critical food source for purple sea stars. This increase in urchin populations had the potential to decimate kelp forests due to overgrazing from the urchins and have spiraling impacts on marine ecosystems.

Our *computational criteria* were influenced by the *Framework* and *NGSS* as well as a computational thinking framework (Weintrop et al., 2016). The phenomenon of the SSWD outbreak was situated within a complex natural system—the marine intertidal environment, which itself is nested within the larger ocean system and impacted by the global climate system. A phenomenon like SSWD that exists within a complex natural system provides ample opportunities for students to engage in systems thinking practices. The phenomenon of SSWD allowed for students to access publicly available data sets, leverage computational tools, and analyze the data in new ways, therefore contributing new scientific knowledge; this also engaged students in the authentic, interdisciplinary work of scientists. There were existing computational simulations and models available that were related to SSWD, climate change, evolution, and natural selection. These were integrated into the design of the unit.

Our *design criteria* were influenced by the partnership's goals, chosen approaches, and constraints, as well as by the members of the design team, the partner biology teacher, and her students. The phenomenon of an outbreak of SSWD was large and complex enough for an extended unit of instruction. The phenomenon was well connected to disciplinary content related to both biology (i.e., evolution, natural selection, genetics) as well as earth and space sciences (i.e., climate change, marine systems). Sea stars, with their short generation time, provide an opportunity for scientists to study natural selection through genetic variation due to changing environmental factors. Publicly available data sets, such as sea star population counts, allele frequency, and sea surface temperatures, allowed for the development of a computationally-rich project in which students took on authentic scientific roles while engaging in open-ended analysis and sensemaking of real scientific data. After months of identifying and analyzing different potential phenomena through instances of knotworking as has been described, and further work by the research team of exploring potential phenomena, the SSWD outbreak appeared to meet the selection criteria for a three-dimensional biology unit.

Phase Three: Designing, Enacting, and Revising the Unit

The third phase was focused on the design and classroom enactment of the unit. Curriculum design was accomplished in partnership with Ms. Ly, as another instance of knotworking. As part of this design work, the CSP research team leveraged some existing tools for curriculum design while also developing their own templates for unit and lesson plan development. These templates were specifically developed for the collaborative design of NGSS-aligned, phenomenon driven science units and were tested and iterated upon during this phase of curriculum design. During design work, the selected anchoring phenomenon was expanded to include phenomena for investigations, project work, and assessment. After the unit was drafted, it was enacted by Ms. Ly with two sections of her biology course. Data was collected from Ms. Ly's ninth grade students during enactment with two classes to provide insights into their experiences with the curriculum. Another temporary collaboration was then formed with a different biology teacher who tested out aspects of the evolution unit in her classrooms. In addition, data collected during the classroom enactments by Ms. Ly and the other biology teacher would later be used to inform the revision of the unit to prepare it for publication and dissemination. Consultations with disciplinary experts were another form of knotworking that were important during the design and classroom enactment of the unit. *Figure 13* presents an overview of this phase of work.

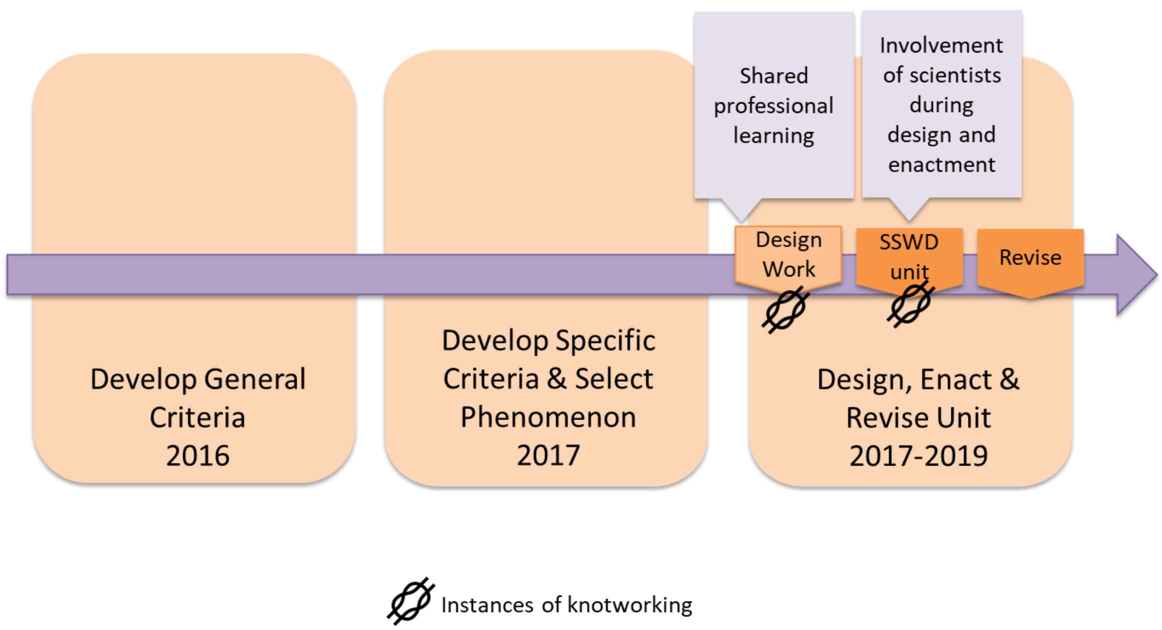

Figure 13. Activity structures across the third phase of designing, enacting, and revising the curriculum unit.

Knotworking for specific curriculum design and pedagogical expertise. In order to leverage specific forms of curriculum design and pedagogical expertise, temporary collaborations were formed with Ms. Ly as well as another biology teacher external to the CSP partnership.

Co-design with partner biology teacher. Our key teacher partnership was our collaboration with Ms. Ly, who was selected by her principal to join the CSP in this work. She was a second year teacher and a Teach for America corps member with a background in biochemistry, biophysiology, and infectious diseases; this was her first time teaching a biology course. Once the research team had selected the anchoring phenomenon of SSWD in June 2017, a learning scientist graduate student with a background as an evolutionary biologist (Klein) and Ms. Ly became the key designers, engaging in co-design practices during Summer-Fall 2017, with Ms. Ly providing feedback. Ms. Ly then enacted the unit with two sections of ninth grade biology students during November 2017-January 2018, engaging in local adaptations. This unit enactment was supported by three researchers and Ms. Cruz, the project manager/instructional coach from Tech Foundation, who was a former high school science teacher (see Chapters Three and Four for descriptions of the supports offered during this enactment). We engaged in research of teacher learning (see Chapter Four) and student experiences (McGowan, 2018) during the unit enactment, but a detailed accounting of these findings is beyond the scope of this chapter. *Figure 14* captures this instance of knotworking with Ms. Ly for the design and initial enactment of the unit.

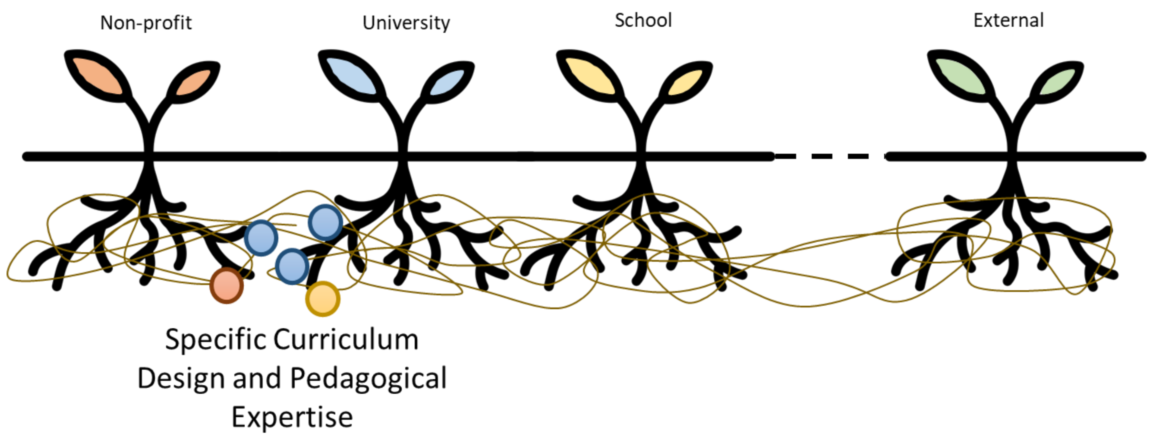

Figure 14. Knotworking for specific curriculum design and pedagogical expertise from the underlying mycorrhizae of the partnership with lead partner teacher.

Piloting with a collaborating biology teacher. Later that spring, an experienced biology teacher external to the CSP partnership with a strong interest in marine biology and PBL volunteered to pilot the computational project portion of the evolution curriculum unit with her high school biology students. This collaboration allowed for a second enactment of the computational project in a new context: a veteran biology teacher facilitating the project with her students in a different state who had no prior connection to the CSP. This teacher enacted the curriculum with minimum support of CSP researchers, which enabled us to test the accessibility of the curriculum templates to teachers as well as to test the computational aspects of the project when enacted in a classroom without additional support from researchers. This collaboration, similar to our earlier collaboration with two other biology teachers, allowed for us to leverage this teacher's *specific pedagogical expertise*. *Figure 15* illustrates the knotworking that occurred for specific design and pedagogical expertise with the three collaborating biology teachers from three different schools, representing collaborative work that occurred at the very beginning and end of designing and revising the evolution unit. In *Figure 15*, colored dots represent the three educational researchers and the three teachers that made up these temporary workgroups.

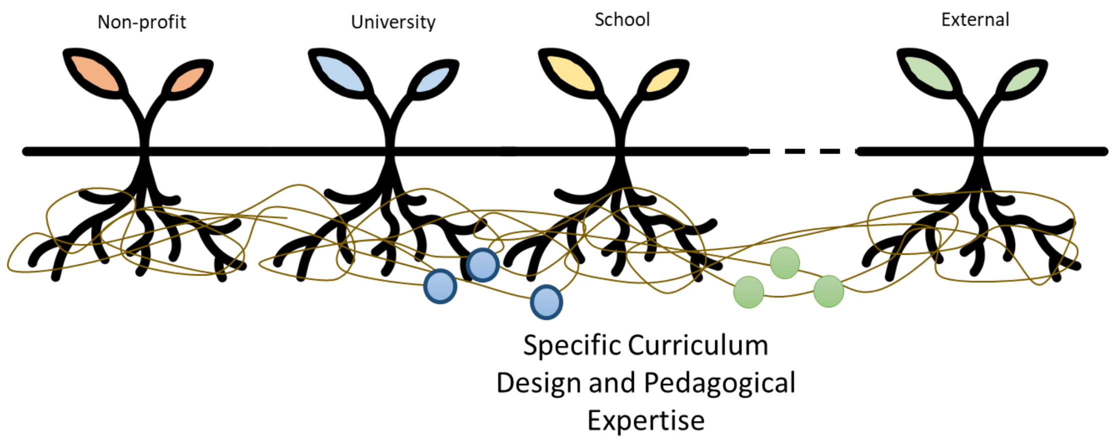

Figure 15. Knotworking for specific curriculum design and pedagogical expertise from the underlying mycorrhizae of the partnership with collaborating biology teachers.

Expanding the anchoring phenomenon to different types of phenomena. The design of a phenomenon-based science unit includes the selection of a unit-level anchoring phenomenon and lesson-level investigative phenomena (Achieve, et al., 2016). However, there are two additional types of phenomena that need to be considered during curriculum design: an assessment phenomenon to be incorporated into a summative assessment of student learning at the end of the unit, and given our PBL approach, a phenomenon to anchor the unit project. *Assessment phenomena* may be used in the design of summative assessment materials. For example, a case that is related to the unit's anchoring phenomenon yet different may be introduced on an end-of-unit exam to assess students' understanding of the underlying scientific principles and demonstration of related scientific practices. For curriculum materials that take a PBL pedagogical approach, a *project phenomenon* may also be included. The project-level phenomena should be tightly linked to the anchoring phenomenon for the unit and should engage students in scientific and engineering practices. Details on each of these types of phenomena in the SSWD unit are described below and summarized in *Appendix K*.

Developing the phenomenon for project work. A critical component of this PBL unit was to engage students in authentic project work. The project was driven by the questions: *How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?* and *What can we predict about the future of the species, given warming trends in sea surface temperatures?* Students were organized into geographic groups according to different regions of the West Coast of the United States that had been impacted by SSWD. Within these geographic groups, each student took on the role of a scientist (i.e., geneticist, geographer, epidemiologist, population biologist, and social scientist). Student would then jigsaw between their research groups of scientists to analyze data sets and their geographic groups to build an infographic that presented their analysis for their specific region of the outbreak. Each geographic group's infographics included: a geospatial map of disease spread over space and time; frequency predictions for the EF1a allele for sites in their region; a line graph showing changes in the numbers of purple sea stars and sea surface temperatures over time; a causal-loop diagram (a type of conceptual diagram) and accompanying explanation of how natural selection is impacting sub-populations of purple sea stars in each region; a prediction about the evolutionary future of the sub-population of purple sea stars supported by evidence from climate modeling analyses; and recommended action steps for mitigating the impacts of SSWD on purple sea stars for their focal region.

Selecting the investigative phenomena. As part of the process of developing the unit, we also selected lesson-level *investigative phenomena* that were the focus of particular lessons within the unit. These investigative phenomena relate to disciplinary core ideas of evolution, natural selection, and climate change, as well as concepts related to sea stars and SSWD. For example, students explore cases of Galapagos finches, Caribbean anoles lizards, and hominids to investigate macroevolution processes through the investigative phenomenon of: *How do changing environmental conditions lead to adaptation, speciation, or extinction of species and sub-populations of species?*

Selecting the assessment phenomenon. In addition, a three-dimensional summative assessment was developed for the unit. It was important that the phenomenon selected for the assessment was in alignment with our overall selection criteria while also challenging students to apply what they had learned through the unit to a similar but different phenomenon. In this written assessment, students were asked to consider and apply their developing understanding of evolutionary processes and ecological impacts, scientific practices, and computational thinking to a scenario that is parallel to the case of SSWD on the West Coast of the United States. The test scenario was set in western North America and featured connections between the mountain pine beetle, pine trees, and warming temperatures due to climate change. On the assessment, students developed a causal-loop diagram (a type of conceptual model) of environmental factors, analyzed a temperature map, and wrote an explanatory model of how the process of natural selection causes changes in traits in pine trees over time. Acknowledging the importance of locally relevant phenomena, the curriculum materials encourage teachers to adapt the scenario to feature species local to their own geographic area that, like the pine trees, has a directly heritable trait being impacted by shifting climate regimes.

Knotworking for specific disciplinary expertise. We engaged in knotworking to build working relationships with disciplinary experts during this design and enact phase. Conversations with professional and citizen scientists who were involved in investigating the West Coast sea star epidemic were important to ensure that the phenomenon met our selection criteria and helped inform the design of the unit. Over eleven organizations provided publicly available data sets that were incorporated into the final project of the curriculum unit. In addition, scientists were engaged in different ways throughout the course of designing, enacting, and revising the curriculum unit. These interactions included: providing a customized data set and answering clarifying questions about these data, deepening the CPS team's understanding of the phenomenon, hosting a field trip to a marine science center, attending students' culminating presentations, and participating in a virtual classroom visit that illuminated for students the authenticity of the scientific practices they were engaging in within their biology classroom. *Figure 16* captures this instance of knotworking, with each colored dot representing an individual who engaged in these consultations.

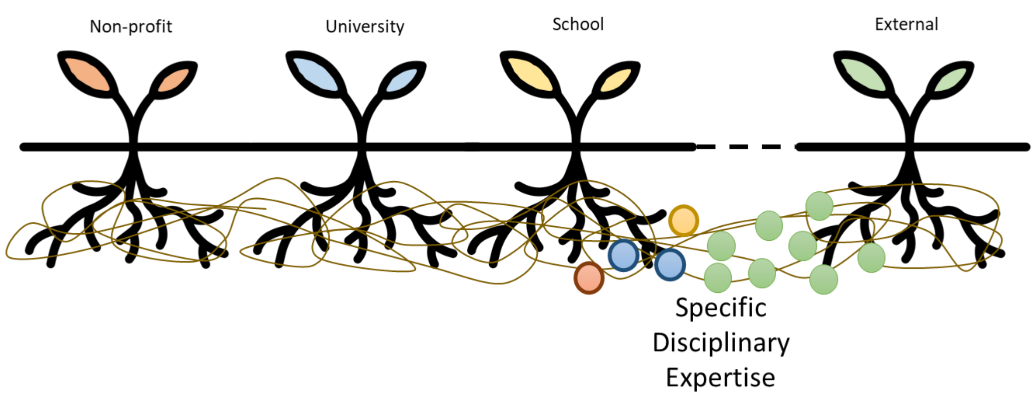

Figure 16. Knotworking for specific disciplinary expertise from the underlying mycorrhizae of the partnership through consultations with scientists.

As an example, correspondences with two authors of a study on sea star disease resistance and a particular genotype became critical to the design of investigations related to allele frequency, providing important scientific data for students to analyze for their final projects. When these scientists later discovered an error in their findings due to a polymerase chain reaction (PCR) artifact, they reached out to the CSP researchers to be sure that the curriculum could be updated. A caveat was added to the lesson plan, creating a teachable moment that illustrates the unfolding nature of scientific research (e.g., data quality issues related to artifacts of research methods). In addition, curriculum materials were shared back with these scientists so that they could see how their data and findings had been incorporated into the high school biology unit. A second example is how two scientists hosted a field trip for students to a local marine science center. These scientists customized their presentation to focus on Sea Star Wasting Disease, provided localized accounts of how the aquarium's collection was impacted by the outbreak, and even provided students with the opportunity to meet a sea star that had become infected with the densovirus and yet survived. One of these scientists later served as an authentic audience member by attending an evening event at Cascade STEM School at which student groups presented infographics as their final projects. A final example is how the lead curriculum designers/researchers (Klein and McGowan) communicated with two scientists involved with field research of Sea Star Wasting Disease. During enactment of the curriculum unit, these biologists participated in a virtual classroom visit with students, talking about the practices and tools they used when engaged in field surveys of sea stars populations. In particular, they discussed the use of computational tools like spreadsheets and statistical software to analyze large data sets, illustrating for students that they were engaged in classroom work that was like that of professional scientists. These collaborations and communications with scientists can be conceptualized as a form of knotworking motivated by the need for deep, disciplinary expertise to inform the design and enactment of the biology unit.

Students' Experiences with the Anchoring Phenomenon

To support and expand upon this narrative, it is also important to consider students' experiences with the selected phenomenon of the SSWD outbreak. What did students experience, feel, and think of the curriculum unit as enacted by Ms. Ly at Cascade STEM School? While a detailed account of students' experiences with the unit enactment is beyond the scope of this chapter, I do wish to highlight several findings specifically related to the selection criteria. (See McGowan, 2018 for additional findings). I summarize the findings of McGowan (2018; Shaw et al., 2018), a member of the CSP research team, who studied students' experiences during the enactment of the SSWD curriculum through the use of ethnographic field methods, classroom observations, focus groups, and student surveys. I also include my own analyses of student data from practical measures surveys (Yeager, Bryk, Muhich, Hausman, & Morales, 2013) that were administered to students at four time points during the unit enactment. Here, I highlight findings related to images of authenticity with the project work, students' experiences with phenomenon fatigue, and, in particular, students' development of empathy for sea stars, which influenced the CSP selection criteria.

Images of authenticity. McGowan (2018), leveraging Polman's 2012 framework of ways that authenticity emerges in project-based learning experiences, explained that learning can be authentic to the learner, authentic to others, or incorporate authentic tools and practices. She found that the selected phenomenon of the SSWD outbreak, as well as the pedagogical structures of the project itself, supported these types of authenticity. Through her analyses, McGowan surfaced three images of authenticity that emerged for students as they engaged in the PBL unit: *context, tools and practices*, and *project roles.* McGowan (Shaw et al., 2018) found that,

> …the authentic and unsettled nature of the Sea Star Wasting Disease phenomena served as an anchor to engage youth in using the tools, data, and practices need to make sense of the project's complexity. Through the use of these tools, youth took on multiple identities as developing experts in the classroom, and agentic citizens within their communities, with regards to the impacts of climate change on wildlife (p. 2).

By featuring a phenomenon situated within a complex system, students were able to develop an understanding of contributing factors, connections, and implications of SSWD. Students took on authentic scientist roles and employed computational tools to analyze real data sets; they were able to identify that they were engaging in the work of scientists.

These findings align with the computational criteria that make up the Selection Criteria for Anchoring Phenomena. McGowan's (2018) three images of authenticity in the project work of the SSWD unit are aligned to the theoretical criteria that make up the Selection Criteria for Anchoring Phenomena, focused on the local, personally-relevant, societally-relevant, authentic, and contemporary nature of the phenomenon. The project phenomenon was viewed by students as authentic through its context, scientific and computational practices and tools, and student roles. However, some students experienced phenomenon fatigue, an impatience or decrease in engagement with the phenomenon itself over time.

Students' experiences with phenomenon fatigue. Ms. Ly engaged in local adaptation of the unit as she prepared for and facilitated instruction—which the research team encouraged as a best practice of curriculum implementation (DeBarger et al., 2017). Some of her adaptations however had the effect of replacing or front-loading inquiry experiences with didactic instruction, such as developing highly scaffolded learning activities and delivering lectures that had the purpose of delivering content and background information before allowing students to engage in scientific practices. Her instructional approach led to lesson plans that as written were intended to take only one class period extending instead for days. While the unit had been designed for a target of six weeks of instruction, her additions and adaptations to the curriculum caused instruction to expand to ten weeks over a three month period. As the unit ballooned in time, students expressed feelings of phenomenon fatigue. When asked on the final survey administered at the end of the unit to provide suggested changes to the unit, an overall theme to student responses was that the unit was too long which resulted in some disengagement from the topic. Survey data showed that six students provided specific suggestions on how and why the unit should be shortened, citing that the extended length of the unit and project lead to feelings of boredom, dread, monotony, and tedium. One student reported that the length of the unit had the effect of "making me feel uneasy on the mere mention of sea stars." Therefore, it is important for curriculum designers to not only keep in the mind the length of a unit during its design, but also during local adaptation and enactment. The curriculum-as-enacted should sustain student engagement with the unit's anchoring phenomenon.

Students' development of a sense of empathy and agentic citizenry. On the very first day of the unit enactment, Ms. Ly asked the class, after they have finished reading a new article about SSWD, "they're not human. Why do we care?" A student, Aamira responded, "they are keystone species in many environments, and they might go extinct." Jasmine later elaborated, "if they were to die off they would change the environment in which they are living, so it could impact other animals." Throughout the SSWD unit, students engaged in multiple learning experiences that allowed them to interact with and develop a scientific understanding of sea stars. On a field trip to a nearby marine science center, they met a purple sea star that had been infected by the densovirus that causes SSWD and surprisingly, had recovered. They learned how the aquarium, which features an open-flow system that uses water from the Puget Sound, used to house over 400 sea stars but then only about 30 remained, with their blood stars and urchins still showing effects from the disease. They heard stories of the devastation to sea star populations on their local beaches. Back in class, students engaged in dissections of sea stars to learn about their anatomical structures. They studied sea star's habitat, role as a keystone species, and evolutionary history. They analyzed real data on West Coast sea star populations collected by professional and citizen scientists. For some students, but not all, these learning experiences provided opportunities to develop an ethos of caring.

Despite some phenomenon fatigue, many students expressed empathy for sea stars and their plight in the face of a changing climate. Purple sea stars as a keystone species are critical for maintaining balance in intertidal ecosystems. The massiveness of the mortality event caused by SSWD was eye-opening for students and sparked a sense of empathy and moral commitment for the invertebrates. One student reported, “I had no idea that climate change played a huge role in sea stars, and other species. It has made me realize that we can help in a lot of ways, reversing climate change, and increase animals’ health.” On the final survey, some students made comments related to the actions people could take in response to their new knowledge about SSWD and climate change. These comments showed that students developed a feeling of agency that they could positively impact sea star health and/or climate change. For example, one student wrote, “before this project I was not sympathetic for the sea stars and it was not my biggest concern but after the project and all of our research I now deeply care about the affects u[s] humans are making on the world [and] I now care about sea stars and their health.” Another student was inspired by what was learned during the SSWD unit to later take up the issue of climate change for an extended research project.

McGowan (2018) refers to this as *a sense of agentic citizenry* that students developed as they learned, through their study of SSWD, how climate change was impacting wildlife. My own analysis of student data from four surveys administered during the enactment of the unit supports this claim of the development of empathy and agentic citizenry. However, not all students developed a connection with sea stars. For example, one student suggested on the third survey that future revisions to the unit should “be more relevant to their lives because we don’t really look at sea stars or care about them much. So maybe you could do it about another more popular animal?"

Through studying the enactment of the unit, an emergent criterion was added to our criteria for selecting scientific phenomenon for science curricula: *Does it provide an opportunity for the development of empathy for non-human animals?* It became important for the design team to think about selecting phenomenon that engaged students in thinking beyond just human impacts, but to include an ecological perspective that engages them in socio-ecological learning and the development of more-than-human empathy (Puig de la Bellacasa, 2017) and a sense of agentic citizenry.

Phenomenon-driven instruction as a new way to learn science. When students engaged in project work that involved computational practices and tools to make sense of data from the SSWD outbreak, they wrestled with a contemporary phenomenon that was unsettled by scientists, as scientists' understanding of the disease, its mechanisms, and the trajectory of sea star recovery was still unfolding. The contemporary, unsettled nature of the phenomenon was surprising and novel to students, and some of them struggled to understand this instructional approach. The excerpt below from the enactment of the biology unit highlights how one ninth grade student, Andrew, struggled with what was to him a new approach to learning science. In this excerpt, Ms. Ly is joined by Ms. Cruz, who is co-teaching the class as part of the CSP supported enactment and who also serves as Ms. Ly's instructional coach. During this class period, students were involved in a jigsaw activity in which they created a timeline of major findings about SSWD after reading a series of articles and viewing videos that stretched back to 2013, the beginning of the epidemic. Ms. Ly asked the class if they had any questions about

SSWD, at which point Andrew questioned why they were reading articles that were several years old.

> Andrew: Why are we basing our studying on an outdated article from 2013?
>
> Ms. Ly: Good question! *[loudly, while pointing at him]*. Okay, does anyone have a theory for why we want to give you this article at this point on day one of the unit?
>
> *[Andrew gets up and walks off camera; Eugene raises hand]*.
>
> Ms. Ly: Any idea why? Hold on, Eugene already talked. Yes, Briana.
>
> Briana: They've probably gone further in research, but you are just introducing us to the topic.
>
> *[Andrew sits back in his chair]*.
>
> Ms. Ly: Yes, did everyone hear that? What did Briana say? What did Briana say? Can someone?
>
> Student in back of room off-camera: Because they're doing research, and this is, you're just introducing the topic to us.
>
> Ms. Ly: Yes. So this is day one of the unit. I am introducing you to the unit. So I want to use an early article to introduce to you what it is like when scientists first found out about this disease. So hopefully we will think that they get far enough throughout the lessons, right—
>
> Ms. Cruz: --right.
>
> Ms. Ly: --and that's what we're going to be progressing through.
>
> Ms. Cruz: That's a good question though.
>
> Andrew: Why don't you just tell us the solution to what happened and then, like, you can have a little section-- give us some background information?
>
> Ms. Cruz: *[Talking over him]* --It is so interesting that you said that because that's assuming that there is a solution. And so, assuming that there is a solution, we may be wrong in assuming that. Maybe they haven't come to a conclusion yet on what's actually happening.
>
> Andrew: Well, if we do look at an article from 2017—

> Ms. Cruz: Mm-hmm *[affirmative]*.
>
> Andrew: --And we find an article that talks about that there is no solution, how has technology and research improved throughout the four years—
>
> Ms. Cruz: Yeah, that would be interesting to talk about.
>
> Andrew: --We don't have to read something from 2013 because that article will provide us with all the background knowledge and information—
>
> Ms. Ly: *[Cutting him off]*. Alright, thank you Andrew.
>
> Ms. Cruz: *[To Andrew at same time as Ms. Ly]* We'll see.
>
> Ms. Ly: For the project-based learning, I actually, we have this upcoming lesson talking about systems thinking. I think that that lesson will answer your question of why we want to look from the beginning—
>
> *[Andrew lowers his head, hunched over his lab table]*.
>
> Ms. Ly: --and go through the process that scientists went through, to find out what—
>
> Ms. Cruz: *[Walks past Andrew, patting his back, says to him quietly]* I understand your frustration though.
>
> Ms. Ly: --they find out at this point. Okay. But for now, let's move on.

In this exchange, Ms. Ly and her co-teacher Ms. Cruz struggle a bit to explain the intention of the activity, and by proxy, the reasons for investigating a contemporary phenomenon.

The next day, Andrew interrupts Ms. Ly during a whole class activity in which they are engaged in a discussion of time lapse maps of the West Coast outbreak of SSWD. Andrew seeks to continue his conversation with Ms. Ly from the day previous, as captured in the excerpt below:

> Andrew: Yesterday I had a question…and I looked the problem up and I realized it doesn't really say anything about, like solutions.
>
> Ms. Cruz: I know.

> Ms. Ly: Alright—*[Seemingly to move along]*.
>
> Ms. Cruz: *[At the same time as Ms. Ly's comment]* What do you think that means, though?
>
> Andrew: I was like, okay, oh, so. Sea stars are still dying and we're going to let them die. Because species go extinct all the time. And the world's going to end very soon. So—
>
> Ms. Ly: --Alright Andrew, I would like for you to hold that comment until after today when some of your group does the reading and then presents their ideas, because one of the articles address your question or your comment very well. Okay? Alright.

Andrew is motivated by the unsettled nature of the anchoring phenomenon to do additional research at home to ascertain if scientists have an answer to what is causing SSWD or if Ms. Ly is just withholding this information from the class. He discovers that there really is not a solution, hitting on the idea that scientific understanding of the phenomena under study is still unfolding. In this excerpt, Andrew introduced a moment in class in which Ms. Ly and Ms. Cruz could have potentially discussed why it is important to study contemporary scientific phenomenon in the classroom, or why he feels that the world is going to end, possibly making some connections to the unit's focus on climate change. However, they do not deeply take up Andrew's struggle and instead Ms. Ly pushes forward with the instructional activity on their agenda.

This missed opportunity shows that when engaging students in phenomenon-based instruction for the first time, educators might consider how to frame for students the reasons for studying contemporary scientific phenomena in the classroom. In the case of SSWD, the answers could not be found online, rather students had to engage in the same kind of work that professional scientists do when investigating a question. This represents a shift in both teaching and learning. When facilitating PBL, phenomenon-based instruction, teachers may need to develop strategies for supporting students' discomfort or frustration with studying an unsettled phenomenon and for highlighting connections with the nature of authentic scientific research. Researchers and curriculum designers, in turn, should consider ways to support teachers and students in this work.

Discussion & Implications

In this paper, I share how members of a design-RPP selected a scientific phenomenon for a NGSS-aligned high school biology unit during a time in which few resources were available for designers engaging in this type of work. Developing a selection criteria and process for selection was a design tension that afforded opportunities for the design team to consider different activity structures and tools to support these processes. Through interwoven cycles of knotworking, ad-hoc groups with specific forms of disciplinary, pedagogical, and design expertise and diverse cross-disciplinary expertise came together as needed to develop ideas, provide critical feedback, and engage in design and enactment work. *Table 8* synthesizes the types of expertise we sought through knotworking, the activity structures in which we engaged, the participants in each ad-hoc collaboration, and the outcomes of engaging in knotworking.

Table 8. Instances of Knotworking for Specific and Diverse Forms of Expertise

Type of Expertise	Activity Structure	Participants	Outcomes of Knotworking
Diverse **Cross-disciplinary** Expertise	Meetings of the Climate Science Working Group	Science teachers, climate scientists, climate science educators, learning scientists	Deeping researchers' understanding of climate change, suggesting potential anchoring phenomena, providing critical feedback on potential phenomena
Specific **Curriculum Design & Pedagogical** Expertise	Prototyping and piloting collaborations with three biology teachers external to the partnership	Learning scientists, science teachers	Developing prototypes of curriculum artifacts, testing feasibility of computational tool, developing and testing prototype assessment format, testing computational aspects of project work
Specific **Curriculum Design and Pedagogical** Expertise	Co-design and supported enactment with Ms. Ly (biology teacher)	Learning scientists, science teacher	Engaging in co-design, local adaptation, and supported classroom enactment, as well as collection of research data
Specific **Disciplinary** Expertise	Consultations with scientists as needed	Learning scientists, professional scientists (biologists)	Providing data sets, answering questions about data, deepening researchers' understanding of phenomenon, hosting a field trip, participating as an audience member, making a virtual classroom visit

Through an iterative process, the members of the CSP developed selection criteria for scientific phenomena that was informed by sociocultural learning theories and the influences of the partnership's members. While specific to the goals of the project, these criteria and our narrative of how we arrived at them may be relevant to other curriculum designers as well. It is important to note that the processes reported in this paper were undertaken as part of a multi-year, grant-funded research-practice partnership. The partnership structure afforded time, diverse forms of relevant expertise, and funding, as well as specific areas of focus for curriculum design activities. The partnership structure also introduced constraints into the design process through its organizing principles and member organization's influences, as well as through the expertise of the researchers and partner teachers.

Design Principles for NGSS-Aligned Science Curriculum Materials

Through the development of this design narrative, particular forms of design knowledge were surfaced that describe how the members of a design-RPP engaged in the selection of scientific phenomena for NGSS-aligned, computationally rich curriculum units. These findings might be helpful for other teams engaged in this type of complex and collaborative design work. In particular, it is important to note that at the time of the Computational Science Project, there were few resources available to support educators and curriculum designers in this process of phenomenon selection (e.g., Achieve et al., 2016; Penuel & Bell, 2016; Research + Practice Collaboratory, 2016; Willard, 2016). The CSP team found much alignment with the recommendations put forth in these resources (as some members of the research team were involved in authoring most of these materials), however the findings of this study point to some recommendations that are not included in these resources. I seek to add to the conversation by sharing this narrative of phenomenon selection through partnership by highlighting four design principles.

Design Principle #1: When co-designing curriculum as part of a research-practice partnership, begin by identifying the organizing principles and influences of all the members of the partnership. Then, develop selection criteria that fits the needs of your particular project. Begin by developing an understanding of what you are trying to do. When curriculum design is approached through partnership, such as in a design-RPP, it is important to identify and understand the variety of influences, priorities, goals, and constraints that each member and organization brings to the partnership, and to the design project. This process requires relational approaches and trust building. This process also needs to be revisited if members of the team transition over time.

Curriculum design within a partnership brings together people in cross-practice and cross-organization collaborations. This work is complex and can be fraught with challenges and full of opportunities (Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallagher, 2013; Severance, Leary, & Johnson, 2016). Understanding the influences, priorities, goals, and constraints of the members of a partnership is part of Edward's (2011) concepts of relational expertise, relational agency, and common knowledge, all of which are important for collaboration in cross-professional and cross-practice work teams. *Relational expertise* is a person's ability to integrate their own professional knowledge with that of other professionals. It involves "recognizing what engrosses others, taking their standpoint and mutually aligning motives so that engagement continues" (Edwards, 2012, p. 25). *Relational agency* is a professional's capacity to collaborate with others. It involves "working with others to expand the 'object of activity' or task being worked on by recognizing the motives and the resources that others bring to bear as they, too, interpret it" and "aligning one's own responses to the newly enhanced interpretations with the responses being made by the other professionals while acting on the expanded object" (Edwards, 2011, p. 34). Members of cross-agency groups work to build *common knowledge*, in which they are able to recognize similar goals, develop a way of talking about problems of practice, and identify and engage with the "categories, values, and motives" of other members of the group (Edwards, 2011, p. 37), and may allow for talking and working across inter-institutional boundaries.

It may be that repertories of relational collaborative practices that developed among the members of the CSP partnership, which in turn helped to develop the mycorrhizal network that connected the partner institutions. One consideration is the role of the university researchers as persistent actors in the partnership, offering a stable partner amidst a continually shifting landscape. During the three years of the CSP, district and school priorities shifted, STEM Academy underwent a major merger with another school, and both schools and Tech Foundation experienced high levels of staff turnover, resulting in transitions among core members of the CSP team. While both schools and Tech Foundation experience high turnover in staff (i.e., principal, teachers, instructional coaches, education managers), the university research team saw the addition of a post-doctoral scholar to the CSP team without any attrition. Other researchers have noted the challenges of continual change and turnover within organizations that make up RPPs and the importance of persistent actors and boundary spanners (Coburn, Penuel, & Geil, 2013; Donovan, Wigdor, & Snow, 2003; Penuel, Coburn, & Gallagher, 2013). Therefore, the processes of partnership building, developing trust and common knowledge, and identifying organizing principles and influences must be revisited when individuals leave and new people join a design-RPP.

Such a relational approach to collaborative work, such as co-design through partnership, would suggest that it is important to begin by getting to know one another and then to develop collegial relationships. However, reviewing the published resources that were available at the time to guide designers and educators in the selection of scientific phenomena for curriculum design (Achieve et al., 2016; Penuel & Bell, 2016; Research + Practice Collaboratory, 2016; Willard, 2016) revealed that this relational approach was missing from those guidance documents—although they are not incommensurable with this idea. While there was much alignment with the recommendations embedded in these resources and the CSP's experience, one thing that was important in the CSP's process but was missing from these other resources was to begin by developing an understanding of the perspectives, priorities, and expertise of partners involved in the curriculum initiative. For example, the CSP's selection criteria included a project-based learning pedagogical approach (a hallmark of the partner school and the historical focus of the university's curriculum development work), the integration of earth and space science standards (a priority of the school district and many others implementing NGSS), the inclusion of local, personally relevant, authentic, and contemporary phenomenon (grounded in past culturally responsive work of the research group and informed by learning sciences literature), and an emphasis on computational thinking practices and tools, especially for youth from groups underrepresented in STEM (an equity priority of the overall project and its funding source). The selection criteria represent an amalgam of the needs of the members of the CSP partnership and their commitments and goals. This collaborative social imagining matches Tatar's (2007) concept that design tensions arise out of the difference between *what is* and *what ought to be*. The CSP's collaboratively and iteratively generated selection criteria captures the partnership members' ideas of what ought to be included in scientific phenomena chosen to anchor instruction.

It is important not to underestimate the time and intentionality needed to establish the partnership and develop a mutual understanding of these organizing influences and priorities; in fact, these may shift and evolve over time in the case of multi-year partnerships, creating a need for teams to develop the ability to be both nimble and reflexive. This ability to surface cross-partner understandings may be supported through the development of activity structures, boundary practices, and tools for relational collaboration specifically created to do this work.

Returning to Engeström's (2008) biology metaphors, this cross-partner boundary crossing provides the nutritious substrate needed for the fungal threads of mycorrhizae to grow. These entwined threads feed, support, and connect the roots of the partner institutions and their members; the tangle of mycorrhizae forms a stable structure that allows for knotworking to occur with specific ensembles of participants timed to the relevant rhythms of the work. Therefore, before engaging in collaborative curriculum design and the particular design task of selecting a scientific phenomenon, it is important for design-partnerships to acknowledge and feed the threads that connect them—to build relational connections into the foundational work of the other. By understanding the partnership's organizing principles and influences and by developing common knowledge through shared learning experiences, the design team can then work to develop selection criteria that fits the needs of their particular project. It is important to understand what makes a good phenomenon for NGSS curriculum in general, as these existing resources point out (e.g., Penuel & Bell, 2016). However, the members of the CSP realized that it was also critical to understand their context and ascertain what makes a good scientific phenomenon for their particular project and cultural and geographic locale. For the CSP team, our priorities led to the development of criteria for the selection of a contemporary scientific NatureCultural phenomena (Suárez & Bell, 2019).

Design Principle #2: When selecting an anchoring phenomenon for contemporary and authentic PBL learning experiences, bring together diverse (e.g., cross-disciplinary expertise) and specific (e.g., curriculum design, pedagogical, and disciplinary expertise) forms of expertise when needed. Think beyond your established partnership or design team to engage in knotworking (Engeström, 2008) by allowing for expansion and contraction in size and expertise. Look for times in which it would be helpful to the design process to bring together people with specific or diverse forms of expertise. Tap your collective social network to develop those connections to experts (e.g., teachers, scientists, technologists).

For example, the CSP benefited from seeking *specific curriculum design and pedagogical expertise* by engaging in co-design of curriculum prototypes and piloting with three experienced biology teachers, allowing for the teachers and designers to engage in some early development of a potential anchoring phenomenon and test out potential curriculum ideas and computational tools. We also sought *specific curriculum design and pedagogical expertise* by creating a design team that partnered educational researchers with backgrounds in biology and curriculum design with our partner biology teacher, Ms. Ly for co-design and enactment of the curriculum unit. By seeking *specific disciplinary expertise* through consultations with scientists, the designers were able to obtain datasets, get guidance on specific issues during curriculum design, and ask for assistance during unit enactment. Likewise, there may be times when it is helpful to invite people with *diverse cross-disciplinary expertise* to form an ad-hoc working group that can provide broad perspectives on a common topic. In this case, the Climate Science Working Group brought together twenty-eight experts with broad expertise to think together about designing climate science-focused curriculum materials. This allowed for collaborative brainstorming, sensemaking of potential anchoring phenomena, and the pooling of related resources.

It was the entangled mycorrhizae of the partnership (Engeström, 2007, 2008) that enabled the design team to engage in knotworking as a strategy to navigate through the design tension of selecting an anchoring phenomenon for curriculum design. These tangled threads included the shared vision and connections between the institutions that made up the CSP partnership, the relational approach to collaboration, the development of collegial relationships among members of the design teams, and the CSP's flexibility and responsiveness amidst a continually changing context. Together, this mycorrhizal foundation enabled knotworking to occur, as needed, to expand the team to seek diverse and specific forms of expertise and to contract back in size to its core.

Design Principle #3: Allow your selection criteria for anchoring phenomenon for contemporary and authentic PBL learning experiences to evolve by remaining open to emergent criteria that may inform future selection processes, in particular by studying the enactment of the designed curriculum materials. Studying the enactment of designed curriculum materials affords the opportunity to learn from students about their own experiences as learners and teachers' experiences as instructors of the materials. Elevating student and teacher voice in this way may reveal insights about the teaching and learning experience that may impact your thinking about what makes a good anchoring phenomenon. The CSP, as a design-based research project, took an iterative approach to developing selection criteria for scientific phenomena. The selection criteria evolved over time, influenced by and acknowledging multiple voices inside and outside of the partnership through knotworking. Once the criteria were developed and applied to help with the selection of the SSWD outbreak as the anchoring phenomenon for a biology unit, the research team continued to study the unit through its design and enactment in the biology classroom. By analyzing student data, researchers surfaced an important finding about students' development empathy for more-than-human animals and a sense of agentic citizenry around issues related to climate change. While the researchers held a stance that these qualities were important, they had not clearly articulated them as part of the selection criteria. It was the students' own reflections on their experiences as learners that led to this iteration of the selection criteria. Therefore, by studying the unit enactment and remaining open to emergent criteria, the team expanded their thinking about what makes a good anchoring phenomenon for the CSP's biology unit. After enactment of the SSWD unit, it was revised by researchers as informed by the outcome of teacher and students' experiences with the enactment. This revision included considering the inclusion of additional learning opportunities for students to develop this sense of agentic citizenry.

Design Principle #4: When designing curricula for contemporary and authentic PBL learning experiences, consider the importance of using curriculum design tools (e.g., templates) specifically created to support shared learning goals. Another important element to the CSP's process not mentioned in published resources for phenomenon selection at the time (Achieve et al., 2016; Penuel & Bell, 2016; Research + Practice Collaboratory, 2016; Willard, 2016) was having design tools that were specifically built for the design of phenomenon-driven science instruction. In co-design work, tools for planning, design, and collaboration can serve as mediating objects that enable joint work at the boundaries of the partnership (Penuel, Allen, Coburn, & Farrell, 2015; Penuel, Coburn, & Gallager, 2013). The CSP research team sampled currently available design tools and then developed their own templates for unit and lesson design. At their very foundation, these templates were created for the design of NGSS-aligned, phenomenon-driven science instruction through the use of collaborative practices within the context of a design-RPP, building upon the history of the research group as well as contemporary efforts underway in science education. The templates were designed so that the resulting curriculum products would be educative, such as including transparency about curriculum stance and approach. Other teams engaged in similar work may want to seek out these types of design templates or look to model curricula to understand how to design for phenomenon-based instruction.

Limitations

Coburn and Penuel (2016) point out that insider accounts of research-practice partnerships may be subject to hindsight bias through retrospective analyses. As I was a member of the CSP research team, this work does represent an insider account. However, I was not present during most of the meetings with the three consulting biology teachers and the Climate Science Working Group, therefore data analysis was centered on generated artifacts, such as field notes and analytical memos, rather than personally experiencing and participating in these events. While this could be seen as a limitation, it did afford me more of an outsider perspective when analyzing these data. However, in other ways, I was able to access the work more fully throughout the research project as I had been directly involved or worked directly with those engaged in the work.

Implications

This study contributes to the current lack of research literature about the selection of a scientific phenomenon and the design of curricula and assessments for teaching phenomenon-driven science instruction, as called for by the *Framework.* The selection criteria and narrative of the CSP's process for phenomenon selection may be of value to researchers, curriculum designers, and science educators engaged in similar work, especially those who design or teach high school biology curriculum, are interested in the socio-scientific issues of climate change and evolution, or who work within the context of a design-RPP. In fact, the selection criteria that were developed and used for the SSWD unit informed the design of a second biology unit focused on infectious diseases and climate change, using avian influenza as the anchoring phenomenon. These two biology curriculum units, as well as the design templates, will be published and widely disseminated to serve as resources for others engaged in this type of work.

This study highlights a particular design tension that was encountered by the members of the Computational Science Project, and therefore contributes to the literature base on design-focused RPPs. As Coburn and Penuel (2016) note, the research community needs studies of dynamics of RPPs, their challenges, and in particular, “how tools, strategies, and routines used by participants address these challenges” (p. 52). The design knowledge and knotworking routines shared in this chapter may be helpful for others engaged in this type of complex, highly collaborative design work.

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Chapter 6

Conclusion

This dissertation seeks to make contributions to learning sciences literature specific to professional learning through collaborative curriculum design within design-RPP structures. As was described in the literature synthesis presented in Chapter Two, there is a need to study the ways in which partnership challenges in design-RPPs are navigated successfully and not, and how tensions during co-design work are negotiated among members of the design team. Moreover, sociocultural perspectives on workplace learning can be employed to develop our understanding of professional learning as people engage in collaborative partnerships to design curriculum materials. Design narratives hold promise as a method for communicating richly descriptive accounts of opportunities and successes, as well as tensions, misadventures, and failures in this complex work. Chapter Two also highlighted the need to investigate professional learning in science teachers as they are brought into design-RPPs as collaborators for curriculum design and enactment practices. In particular, more research is needed to understand how co-design initiatives may support or constrain professional learning for early-career science teachers, and how partnership activities are impacted by the specific needs of these novice teachers.

The studies presented in the three empirical chapters were each inspired by tensions in project work that were surfaced and identified using the design tensions framework (Tatar, 2007). First, at the level of the partnership, Chapter Three grappled with the tension that occurred across the spheres of the partnership of spanning institutional, sociocultural, and professional boundaries within the CSP in order to carry out our joint work. Second, at the level of the teacher, Chapter Four examined the tension of supporting co-design practices and curriculum enactment when the key teacher-designers are early in their career and still developing their own classroom practices. Finally, at the level of the design team and the designed curriculum itself, Chapter Five described how the CSP partners developed selection criteria and engaged in selection processes in response to the design tension of selecting scientific phenomena to anchor units of instruction.

In this concluding chapter, I first introduce a new conceptual framework that can be used for understanding professional learning through co-design activities within the specific structure of a design-RPP. By employing this framework, I show how it pertains to each of the three empirical chapters and summarize the major findings across these studies.

A New Conceptual Framework for Professional Learning

As these empirical chapters have shown, co-design within design-RPPs is complex work. As a contribution to the literature, I present a new conceptual framework for understanding how professionals learn through collaborative curriculum design activities within the structure of design-RPPs. The Framework for Professional Learning through Design in Partnership is a conceptual and analytical tool for thinking about, designing for, and developing understandings of what and how professionals learn when they engage in co-design within a design-RPP. In this case, professionals come together in inter-institutional and cross-practice partnerships to engage in joint work; this collaborative work occurs at and often across institutional, sociocultural, and professional boundaries. The Framework provides a new conceptual and analytical tool for researchers engaged in these types of partnerships.

The Framework for Professional Learning through Design in Partnership extends existing conceptual and descriptive models of teacher learning through curriculum use and curriculum design (previously described in Chapter Two). These earlier models include Brown's (2009)

Design Capacity for Enactment Framework, Clarke and Hollingsworth's (2002) Interconnected Model of Professional Growth, Engeström's (2001) concept of expansive learning, and Binkhorst, Handelzalts, Poortman, and van Joolingen's (2015) Integrated Descriptive Framework for Teacher Design Teams. However, as described in Chapter Two, these existing tools are limited in their ability to fully capture the complexity and nuances of professional learning through collaborative design activities, and in particular, none of these prior models are situated within the organizational structure of a research-practice partnership.

A diagram of the Framework for Professional Learning through Design in Partnership is provided in *Figure 17*. The Framework consists of four major parts: Influences, Practices, Mediating Processes, and Outcomes. These four parts of the Framework represent a temporal trajectory through the experience of individuals participating in co-design within a design-RPP. Outcomes can build on one another and may loop back to alter the Influences, creating a dynamic and living model that begins to capture the complexity of partnership work. Located within the four parts of the framework are four domains, inspired by the work of Clarke and Hollingsworth (2002): the Personal Domain, the Contextual Domain, the Domain of Practice, and the Domain of Results.

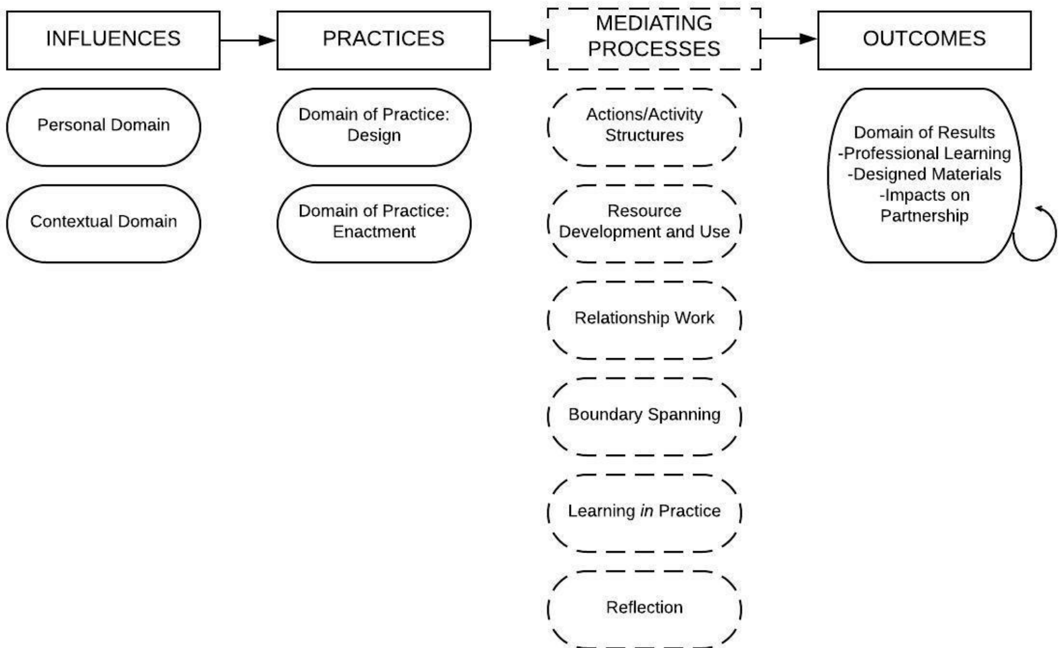

Figure 17. The Framework for Professional Learning through Design in Partnership is a conceptual and analytical tool for understanding collaborative design within the complex ecosystem of design-focused research-practice partnerships.

Within the Framework, *Influences* can be thought of as the inputs into the ecosystem of the design-RPP. This part of the Framework includes the Personal Domain and the Contextual Domain. The Personal Domain includes the personal and professional resources of the individuals that participate in the partnership, including their knowledge and existing expertise, beliefs, goals, professional identity, and personal background. For teachers, this would also include their training through teacher preparation, certification, and induction programs. The Contextual Domain encompasses what Clarke and Hollingsworth (2002) describe as the change environment. It includes external factors, such as political and economic climates (e.g., a science reform climate), national and state learning standards, funding priorities, and professional norms. Conceptualizing a RPP as a multi-sphered partnership, this domain also encapsulates the professional culture and the vision and goals of each institution which makes up the partnership. It is important to note that often the Contextual Domain is not static; rather it shifts and evolves throughout the lifespan of a design-RPP. Therefore, it is important with the Framework to continue to revisit the impact of the influences from this Contextual Domain as it shifts over time.

Practices encompasses approaches to the major work activities that unfold in a design-RPP. This part of the Framework includes two domains of practice: design and enactment. Within the Domain of Practice of design work, the focus is on professional learning through the process of co-design. This includes the practices of curriculum design, including developing design processes, tools, and cooperative work practices, as well as writing instructional materials and revising them based on the results of classroom enactments and expert reviews. Within the Domain of Practice of enactment, the focus is on professional learning that occurs through the process of enacting designed products, innovations, and interventions in actual learning contexts with learners—such as classroom enactments in K-12 schools. This includes both the instructional practices of facilitating the materials with students, as well as the development of supports to help teachers with the enactment. Reflexive tools and practices may also be employed to help teachers and researchers learn from the enactment, which in turn can impact revisions to the curriculum materials. This lens is focused on professional learning *in* practice.

Mediating Processes are the process factors that may serve to mediate activity between Practices and Outcomes—between the Domains of Practice and the Domain of Results. In the Framework for Professional Learning through Design in Partnership, Mediating Processes to consider include: actions and activity structures; resources development and use; relationship work; boundary spanning; learning *in* practice; and reflection. Not all of these Mediating

Processes will be salient to all design-RPPs or all co-design activities. However, it can be helpful to think about how cognitive, material, social, and relational processes may mediate activity within the partnership.

Outcomes encompasses the Domain of Results, which consists of the products and consequences of partnering processes and collaborative work. This part of the Framework includes outcomes related to professional learning within the Personal Domain, outcomes related to the designed materials, and impacts on the partnership. The outcomes of the Personal Domain are focused on professional learning as a result of practice. Within this domain, professional learning can be understood as it develops for teachers, researchers, disciplinary experts, and other collaborators. For instance, development of expertise, shifts in professional identity, and changes to professional practice are potential outcomes related to the Personal Domain. These outcomes, then, loop back to the Personal Domain within the Influences section of the Framework, potentially affecting future collaborative endeavors. Outcomes related to the designed materials includes the quality of curriculum materials produced, tested, revised, and published through the partnership work. It is through the enactment and testing of these materials that outcomes related to student learning can be evaluated, which can then influence the perceived quality of the curricula. Impacts on the partnership itself is another dimension within the outcomes section of the Framework. Similar to Tatar's (2007) concept of "as created situations", changes to the partnership itself may occur, as guided by the Influences, Practices, and Mediating Processes. Potential impacts to the partnership include transitions in personnel and partner organizations, shifts in vision, approaches, and stances, and changes to the research endeavor. Therefore, these outcomes then loop back to the Contextual Domain within the Influences section of the Framework, potentially impacting future partnership activities.

Uses of the Framework. The Framework for Professional Learning through Design in Partnership, like Clarke and Hollingsworth's (2002) model, can be used by researchers as a predictive or analytical. Researchers can employ the Framework as a tool when engaged in early design processes—such as developing initial ideas for a design-RPP, engaging in early partnering processes, and conceptualizing the designed materials they may produce. The Framework can be used to engage with "how might we?" questions. In this way, they can make conjectures about the activities and learning that may unfold, and how they may develop structures, routines, and tools to support these processes and their desired outcomes. For example: how might we change this activity structure?; how can we disrupt this pattern?; or what if we introduce a new routine? Likewise, the Framework can be leveraged as an analytical tool. In this way, it can be used to develop analytical descriptions of data, aiding researchers in the posing and answering of "how did?" and "what happened when?" questions.

The Framework for Professional Learning through Design in Partnership can be used holistically to understand the complex factors that influences, inform, and mediate collaborative design work within design-RPPs. In this case, a researcher would attempt to map all the domains and mediating processes in the ecosystem of the partnership. The Framework can also be used with a finer grain of analysis to understand how a particular individual (e.g., a science teacher) or a role category (e.g., all collaborating teachers) engages in professional learning through collaborative design work. In this case, the researcher would follow a chain (P. Bell, personal communication, 2015) or story of an individual or role category through the Framework, from Influences to Outcomes. An example of an analytical chain for each of the three empirical chapters in this dissertation is integrated into the summary of major findings below.

The Framework could be employed in other ways, opening up future research possibilities with the data corpus of the CSP across its four year lifespan. For example, the Framework could be helpful in understanding connections between teacher learning, the quality of the designed curriculum materials, and student learning outcomes. Questions could be asked about the professional learning that occurred among the disciplinary experts that were involved in design activities. The Framework could be used to trace how specific contextual factors—and their shifts over time—influenced the other connected factors within partnership activities. The Framework could be used to interrogate how patterns of hierarchy, status, and power could be disrupted with the introduction of regular and intentional reflection practices. Likewise, the Framework could be useful for thinking through the design, organization, and partnering processes of future design-RPP initiatives. As this Framework is employed to help understand these types of questions, it can be expanded and refined as a conceptual tool.

Major Findings

In this section, I share a summary of the major findings from the three empirical chapters that make up this dissertation. This includes findings from a case study of a collaborator within the CSP partnership, a case study of an early-career science teacher involved in CSP co-design activities, and a design narrative of the design team's experiences developing criteria and a process for selecting phenomena to anchor instruction in science curriculum materials.

Role Fluidity across (Im)permeable Boundaries of Partnership

The micro-ethnographic case study of Ms. Cruz presented in Chapter Three offered an example of the multiple roles that teachers and others may take on when they are invited to participate in co-design endeavors—work that engages them outside of their home institution—and the struggle to balance those roles and competing responsibilities in order to carry out that work. Teachers are commonly brought into design-RPPs and asked to take on roles in addition to their teaching roles. Specifically, this study sought to understand what roles Ms. Cruz took on in this design-RPP, including how she attempted to balance multiple, shifting roles. Ms. Cruz had to balance the responsibilities related to the co-design work with her other roles across two other institutions in the partnership, with competing goals. Ms. Cruz actively created and implemented strategies for this complex balancing work, however, several episodes and her own language choices during interviews revealed a mismatch between how Ms. Cruz and the research team were operationalizing important components of the project's vision and approach to the work. It became apparent that Ms. Cruz had not been fully supported by the research team in areas of professional learning that were important for alignment of vision and approach to the collaborative work. The multiple, competing demands on her time through her multiple roles across institutions served as a barrier to her deep engagement in shared learning and development of common knowledge. These competing demands also contributed to her burnout and resignation from her position.

In addition, Ms. Cruz's case revealed the complexities of design work when the contextual domain is in a state of constant change and major disruptions. Through Ms. Cruz's case, we see how boundaries are influenced by institutional histories and shifting contexts, and that because of this, the roles that are available and needed may change over time. Role fluidity may allow a collaborator to assume different roles in response to shifting needs and interests. However, there may be a threshold for role fluidity which marks the number or types of roles an individual may be able to productively balance. Researchers, collaborators, and school administrators might consider if there is value in re-mediating (Bang & Vossoughi, 2016) or reimagining roles and making role categories porous, or in limiting some role categories in order not to overextend the individual placed in a boundary spanning position. In particular, the role category of "researcher" may feel less available to someone outside of the research team due to professional boundaries.

Researchers must acknowledge that role porosity and re-mediations takes opportunity, trust, support, as well as time to develop. Moreover, researchers should also consider when it is productive to have a boundary spanning position within a partnership, and when instead researchers should be directly involved in developing relationships and crossing boundaries themselves. Researchers who develop these types of partnerships should carefully consider the institutional, sociocultural, and professional structures and practices that need to be in place to support this complex work and the people charged to do it. This lens includes examining issues of power, status, and authority among the members of the partner institutions and how these power dynamics might serve to support an individual who needs to cross boundaries, or may at times function as barriers that inhibit their work.

The Framework for Professional Learning through Design in Partnership is useful for tracing Ms. Cruz's professional learning. The analytical chain for Chapter Three (shown in *Figure 18*) centered on the case of Ms. Cruz, her attempts at boundary spanning, and the multiple roles she assumed in the CSP partnership, and in particular Ms. Cruz's professional learning and impacts to the partnership.

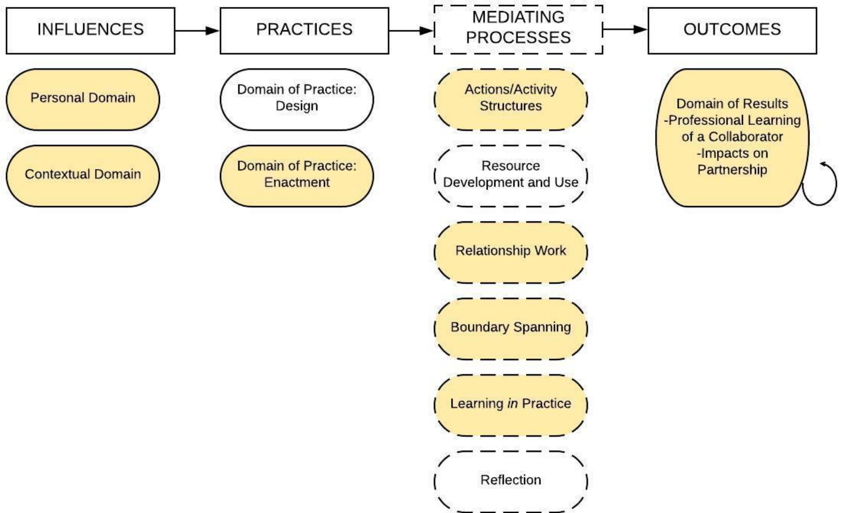

Figure 18. Analytical chain for the Ms. Cruz case study using the Framework for Professional Learning through Design in Partnership.

Ms. Cruz's narrative included the influences of her Personal Domain and Contextual Domain. Particularly salient in the Personal Domain were the expertise, beliefs, and professional identity she brought to her work, and her institutional and insider knowledge. The complex and ever-shifting context of the school merger introduced challenges into the Contextual Domain, as did Ms. Cruz's transitions through different jobs and role categories. Ms. Cruz's narrative focused on the co-planning, co-teaching, and debriefing practices she developed with researchers in support of Ms. Ly in the Domain of Practice of curriculum enactment. These activity structures also acted as Mediating Processes in her work with Ms. Ly. Other salient Mediating Processes included how she learned in practice throughout her three years of participation in the CSP and through moving through multiple roles, her relational approaches to collaborative work and engagement in interactional processes, and her attempts at inter-institutional boundary spanning. The Outcomes included Ms. Cruz's own professional learning through practice and impacts on the partnership.

Professional Learning of an Early-Career Science Teacher through Co-Design

The case study presented in Chapter Four shared the experiences of Ms. Ly, an early-career science teacher who participated in CSP design activities. This case study suggests that a design-RPP can function as a context for teacher professional learning and the development of multiple forms of expertise. I note that design-RPPS create a new type of context for teacher learning, which I call a *designer setting*, in which a teacher's professional learning pathway includes activity structures and opportunities for learning that are unique to co-design work. In this chapter, I argued that while early-career teachers themselves may see value in participating in a co-design initiative and benefiting from the support of relationships that extends outside of their school building, researchers need to proceed cautiously with novice teachers. The involvement of early-career teachers in intensive design-RPP initiatives needs to be undertaken carefully, with an acknowledgement that special routines and supports may need to be developed, which have the potential to distract from the goals of the co-design initiative.

The research base is thin on accounts like this one that center the experiences of early-career science teachers' involvement in design-RPPs and the impacts to the teachers and the project. Further research is needed to understand how to structure design-based RPPs to create a supportive *designer setting* for teacher professional learning. In particular, the research community needs to study the risks and benefits of involving early-career teachers in co-design initiatives.

Applying the Framework for Professional Learning through Design in Partnership, the analytical chain for Chapter Four (shown in *Figure 19*) focused on Ms. Ly's teacher professional learning through participation in co-design activities within the CSP partnership and how the involvement of early-career teachers impacted the partnership.

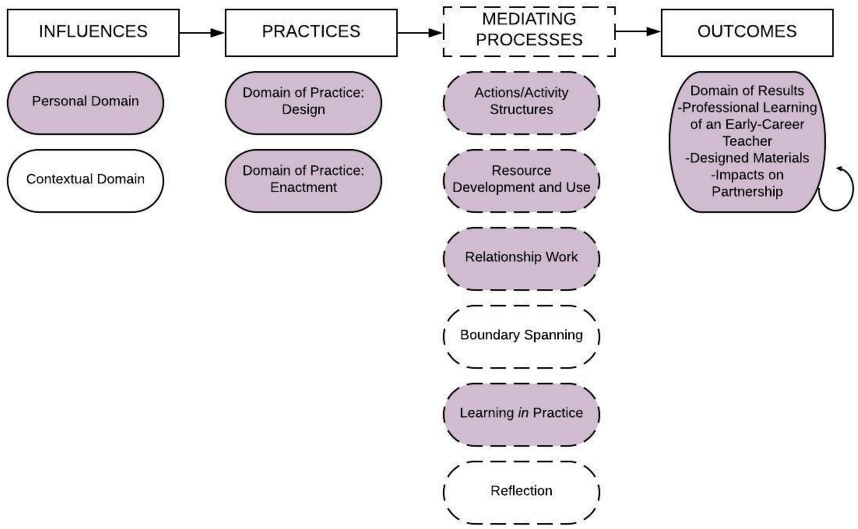

Figure 19. Analytical chain for the Ms. Ly case study using the Framework for Professional Learning through Design in Partnership.

Ms. Ly's narrative was influenced by the personal and professional resources of her Personal Domain, including her teacher preparation training, and the challenges presented by the Contextual Domain of the school and her classroom, as well as the disruption of the school merger. Ms. Ly was heavily involved in the Domain of Practice of co-design work, local adaptation, and enactment of two biology units in her classroom. By focusing on her professional learning, the salient Mediating Process was how she learned in practice through co-design and enactment, and the influence of relationships with Ms. Cruz and the researchers. Activity structures (i.e., co-design, co-teaching, debriefing) and material resources (e.g., curriculum materials, instructional tools) were also important mediators to these practices. The Outcomes of Ms. Ly's chain were focused on her own professional learning and impacts on the partnership. Ms. Ly cited her participation in CSP activity structures as helping her to develop expertise in facilitating project-based, phenomenon-driven learning experiences and in incorporating the use of computational practices and tools in her courses. She also expanded her concept of curriculum design to include cycles of design-feedback-adaptation. Ms. Ly also experienced a temporary shift in her teaching practice as she took on more of a facilitator—rather than lecturer—role during students' involvement in project work. Impacts to the partnership included shifts and design pivots that were made to accommodate Ms. Ly's needs as an early-career teacher. These pivots along with Ms. Ly's local adaptations and pedagogical approaches also impacted the curriculum materials and students' experiences during the enactment.

Navigating Tensions in Co-design through Knotworking

The design narrative of CSP design work presented in Chapter Five shared how members of a design-RPP selected a scientific phenomenon for a high school biology unit during a time in which few resources were available for designers engaging in this type of work. Developing selection criteria and processes for selection was a design tension that afforded opportunities for the design team to consider different activity structures and tools to support these processes. Through interwoven cycles of knotworking, ad-hoc groups with specific forms of disciplinary, pedagogical, and design expertise and diverse cross-disciplinary expertise came together as needed to develop ideas, provide critical feedback, and engage in design and enactment work.

Through the development of this design narrative, particular forms of design knowledge were surfaced that describe how the members of a design-RPP engaged in the selection of scientific phenomena for NGSS-aligned, computationally rich curriculum units. These findings might be helpful for other teams engaged in this type of complex and collaborative design work. These four design principles include:

- **Design Principle #1:** When co-designing curriculum as part of a research-practice partnership, begin by identifying the organizing principles and influences of all the members of the partnership. Then, develop selection criteria that fits the needs of your particular project.

- **Design Principle #2:** When selecting an anchoring phenomenon for contemporary and authentic PBL learning experiences, bring together diverse (e.g., cross-disciplinary expertise) and specific (e.g., curriculum design, pedagogical, and disciplinary expertise) forms of expertise when needed.
- **Design Principle #3:** Allow your selection criteria for anchoring phenomenon for contemporary and authentic PBL learning experiences to evolve by remaining open to emergent criteria that may inform future selection processes, in particular by studying the enactment of the designed curriculum materials.
- **Design Principle #4:** When designing curricula for contemporary and authentic PBL learning experiences, consider the importance of using curriculum design tools (e.g., templates) specifically created to support shared learning goals.

This study contributes to the research literature about the selection of a scientific phenomenon and the design of curricula and assessments for teaching phenomenon-driven science instruction, as called for by the *Framework for K-12 Science Education* (National Research Council, 2012). The selection criteria and narrative of the CSP's process for phenomenon selection may be of value to researchers, curriculum designers, and science educators engaged in similar work, especially those who design or teach high school biology curriculum, are interested in the socio-scientific issues of climate change and evolution, or who work within the context of a design-RPP.

Using the Framework for Professional Learning through Design in Partnership, the analytical chain for Chapter Five (shown in *Figure 20)* centered on researcher learning as we grappled with a particular design tension within the CSP's co-design processes and its impacts on the partnership.

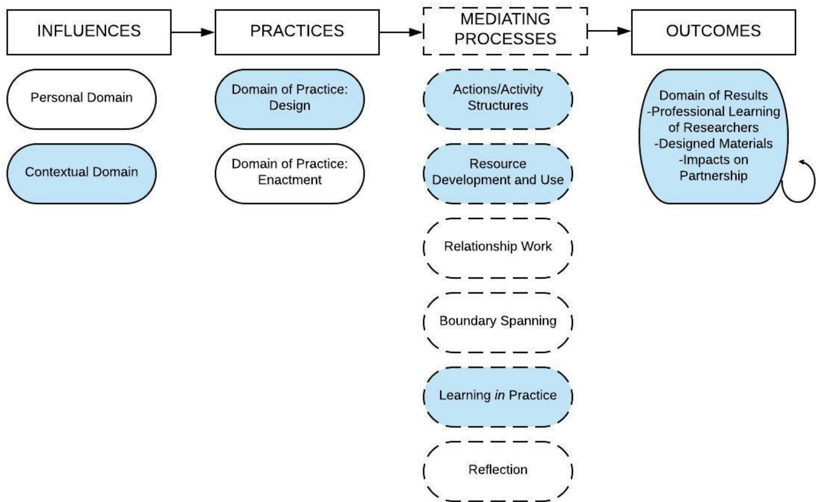

Figure 20. Analytical chain for the phenomenon selection design narrative using the Framework for Professional Learning through Design in Partnership.

This design tension narrative focused heavily on the influences of the Contextual Domain on the Domain of Practice of curriculum design for the biology evolution unit. A core Mediating Process that emerged was the development of the activity structure of knotworking (Engeström, 2008) in order to resource the partnership with diverse and specific forms of expertise. The Outcomes of this narrative was researcher learning about different activity structures to elicit needed expertise and their impacts on the designed product and the partnership itself. *Table 9* synthesizes the types of expertise that the CSP design team sought through knotworking, the activity structures in which we engaged, the participants in each ad-hoc collaboration, and the outcomes of engaging in knotworking.

Table 9. Instances of Knotworking for Specific and Diverse Forms of Expertise

Type of Expertise	Activity Structure	Participants	Outcomes of Knotworking
Diverse **Cross-disciplinary** Expertise	Meetings of the Climate Science Working Group	Science teachers, climate scientists, climate science educators, learning scientists	Deeping researchers' understanding of climate change, suggesting potential anchoring phenomena, providing critical feedback on potential phenomena
Specific **Curriculum Design & Pedagogical** Expertise	Prototyping and piloting collaborations with three biology teachers external to the partnership	Learning scientists, science teachers	Developing prototypes of curriculum artifacts, testing feasibility of computational tool, developing and testing prototype assessment format, testing computational aspects of project work
Specific **Curriculum Design and Pedagogical** Expertise	Co-design and supported enactment with Ms. Ly (biology teacher)	Learning scientists, science teacher	Engaging in co-design, local adaptation, and supported classroom enactment, as well as collection of research data
Specific **Disciplinary** Expertise	Consultations with scientists as needed	Learning scientists, professional scientists (biologists)	Providing data sets, answering questions about data, deepening researchers' understanding of phenomenon, hosting a field trip, participating as an audience member, making a virtual classroom visit

Moreover, researchers developed criteria for selecting contemporary, computationally-rich, scientific phenomena for anchoring units of instruction that aligned to the shared learning goals of CSP partners. This selection criteria for anchoring phenomena included: *theoretical criteria* guided by learning theory; *computational thinking criteria* guided by the *Framework for K-12 Science Education* (National Research Council, 2012), learning standards, and the CSP's computational thinking framework; *design criteria* guided by shared instructional goals, approaches, and constraints; and *emergent criteria* guided by students' experiences during the enactment of the unit. Student's experiences with the curriculum unit-as-enacted were also explored as an outcome of this work. By tracing the analytical chain through all four parts of the Framework, we can see how researcher learning and the biology curriculum unit were the outcomes of particular Influences, Practices, and Mediating Processes.

Implications

This research contributes to the literature base on collaborative approaches to the design of reform-oriented science curriculum materials within the structure of design-focused research-practice partnerships. These findings describes the highly complex nature of co-design as a work activity that occurs within the context of inter-institutional, cross-practice partnerships. Through the presentation of two case studies and a design narrative, this research shares descriptive accounts of the behind-the-scenes activity within design-RPPs and the experiences of the people engaged in these types of endeavors. In particular, the empirical studies that make up this dissertation share findings related to opportunities for professional learning within a co-design initiative, with a focus on collaborator, teacher, and researcher learning. The Framework for Professional Learning through Design in Partnership offers a new conceptual tool that extends earlier work of scholars focused on teacher professional learning through the design and use of curricula and that can be built upon by others. The Framework offers researchers a tool for developing understandings of how professionals learn when they engage in co-design within the ecosystem of a design-RPP.

Design-RPPs often ask teachers to take on roles during the collaborative design, enactment, and revision of curriculum materials that are outside of and in addition to their regular roles as teachers. Competing responsibilities across multiple roles may be difficult to balance. At times, teachers or other collaborators may be engaged in articulating work across the institutions that make up a partnership. Therefore, it is important for researchers, schools, collaborators, and funders to recognize the difficulty of balancing these multiple roles and the challenges of articulating work processes across institutions. Early in their partnering processes, partners could intentionally develop routines and tools to better support partner teachers and collaborators, and revisit these often as the context and needs shift. In addition, it is important to recognize the responsibility of partner institutions in also supporting these partner teachers and collaborators. These findings also bring up questions related to the engagement of early-career teachers in co-design work. Researchers need to balance the goals of the design-RPP and the quality of the designed products with the specific structures, routines, and tools that may need to be developed to support the professional learning of early-career teachers engaged in this work. In addition, when forming design-RPP collaborations, it is important for the collaborators to decide if the focus of the partnership is on professional learning with curriculum design as a mediating practice, or if the focus is solely on the designed products themselves. Finally, this research also shares researchers' learning through a presentation of the design knowledge that was gained as the members of a design-RPP engaged in the selection of scientific phenomena for NGSS-aligned, computationally rich curriculum units.

The *Framework for K-12 Science Education* (National Research Council, 2012) along with the *Next Generation Science Standards* (NGSS Lead States, 2013) and related state standards have created a need for the design of reform-oriented science curriculum materials. All children deserve access to high quality curriculum materials that are relevant, contemporary, authentic, and interesting to them. Design-focused research-practice partnerships offer a promising context for this design work. Design-RPPs result in the production of needed curriculum materials, while also serving as research contexts and providing rich opportunities for professional learning. Researchers must continue to interrogate the design-RPP model to expand our understandings of the opportunities and challenges of this form of collaborative design work.

References—Chapter 6

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Appendices

Appendix A

Appendix A: *Summary data plan for empirical chapters.*		
Chapter Three **Role Fluidity Across (Im)permeable Boundaries of Partnership: A Case Study of a Boundary Spanner within a Research-Practice Partnership**		
Research Question: *What roles did a person positioned as a boundary spanner take on in a design-based RPP, and who benefited from her participation? How did she cross the boundaries of the respective institutions in the partnership and in what ways was she constrained in this work?*		
Analytical Sub-questions	**Data Sources**	**Data Analysis Methods**
What challenges or barriers did Ms. Cruz encounter when engaged in inter-institutional, cross-practice collaboration? How did she express these boundaries, explicitly and implicitly? *How did she (un)successfully navigate these boundaries? What boundary practices (tools and routines) developed during her instances of boundary crossing and negotiation? What was the role of hierarchy and power structures in influencing her (in)ability to cross boundaries?* *How was Ms. Cruz as the boundary spanner impacted by her participation in the design-RPP? What changes did she experience related to her*	**Key Data:** 5 Interviews with Ms. Cruz (video recordings, field notes, analytical memos). **Supporting Data:** 6 Classroom observations of co-teaching (field notes, video/audio recordings, analytical memos). 15 Debrief sessions (field notes, audio recordings, analytical memos). Debrief spreadsheet (31 entries). Collaborative CSP project planning meeting notes and critical email correspondences (weekly, over three years).	**Methodology:** Design-based research Single case study Micro-ethnography **Methods of Analysis:** Ongoing analysis with analytical memos Content analysis and discourse analysis with open coding for *in vivo* and *a priori* concepts Thematic analysis through axial coding Analytical memos Triangulation

<table>
<tr><td>professional learning, identity, agency, and interest?</td><td></td><td></td></tr>
<tr><td colspan="3">Chapter Four
Early Career Science Teachers as Curriculum Designers: Professional Learning of Novice Teachers through Co-Design</td></tr>
<tr><td colspan="3">Research Questions: How did the involvement of an early-career science teacher in co-design, local adaptation, and reflective enactment of curricula benefit and challenge her professional learning, development of various forms of expertise, and professional practice? and Should early-career teachers be asked to take on critical partner roles in design-RPP endeavors?</td></tr>
<tr><th>Analytical Sub-questions</th><th>Data Sources</th><th>Data Analysis Methods</th></tr>
<tr><td>What forms of expertise did Ms. Ly bring to the co-design work and what forms of expertise did she develop through the experience?

What changes occurred in Ms. Ly's professional identity, agency, and interest through her active participation in a design-RPP? What may have shaped or supported these changes?

How does the participation of an early-career teacher in a design-based RPP shape the project? What tools and routines specifically supported novice teachers in this work?</td><td>Key Data:
Interviews with teachers (Ms. Ly 3, Mr. Sherman 2)

Supporting Data:
Interviews (Ms. Cruz 5, Ms. Eider 2)

Field notes, video/audio recordings, and analytical memos for debrief sessions (15 total)

Debrief spreadsheet with 31 entries

Co-design artifacts

Curriculum artifacts (chemistry unit, two biology units)

Classroom observations (22 of biology unit)

Critical email messages between teachers and researchers</td><td>Methodology:
Design-based research

Case study

Methods of Analysis:
Content analysis with open coding for in vivo and a priori concepts

Thematic analysis with axial coding

Analytical memos

Triangulation

Cross-case comparison</td></tr>
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<tr><th colspan="3">Chapter Five
Navigating Tensions in Co-design through Knotworking: Selecting Contemporary Scientific Phenomena for High School Biology Curriculum</th></tr>
<tr><td colspan="3">Research Questions: What processes and criteria for phenomenon selection should be used for the design of high school biology curricula? In particular, what selection criteria and processes of selection would support the design of curricula focused on a contemporary, locally-relevant, and computationally-rich scientific phenomenon that engages students in the socio-scientific issues of global climate change and evolution?</td></tr>
<tr><th>Analytical Sub-questions</th><th>Data Sources</th><th>Data Analysis Methods</th></tr>
<tr><td>What processes did the design team engage in in order to develop criteria and select an anchoring phenomenon?

In what ways was the criteria influenced by the different members of the CSP partnership?

What forms of expertise were needed throughout this process of criteria development and phenomenon selection?</td><td>CSP Weekly Meetings: Notes from weekly project meetings. These notes were co-written by attendees in a cumulative Google document during weekly project meetings.
(2016: 71 pgs; 2017: 63 pgs).

Climate Science Working Group Meetings: Field notes, analytical memos, and documents (agenda, slide deck, working documents) from three working group meetings.

Consulting Teacher Meetings: Field notes, analytical memos, and design documents from two co-design sessions and classroom enactment with two consulting biology teachers.

Project Archives: Various sources documenting partnership formation, funding, and reporting.

Practical Measures Surveys: Online surveys were administered to students</td><td>Methodology:
Design-based research

Design narrative and design principles

Survey research

Methods of Analysis:
Ongoing analysis and analytical memos.

Retrospective content analysis with open coding for in vivo and a priori concepts.

Thematic analysis using axial coding.

Survey analysis: Descriptive statistics, coding of open-ended responses, and analytic memos.

Triangulation.</td></tr>
</table>

	at four time points during the unit enactment to elicit students' experiences, reflections, and suggestions for the unit. Constructs were repeated to allow for comparison over time.	

Appendix B

Appendix B: *Three curriculum units were designed by the Computational Science Project using collaborative approaches to curriculum design.*

	Chemistry of Early Earth's History Chemistry Unit	**Sea Star Wasting Disease: Impacts of Climate Change on Evolution & Biodiversity** Biology Extended Unit	**Climate Change & Infectious Disease Outbreaks** Biology Mini-Unit
Unit Length (as written)	4-6 weeks	6-8 weeks	1-2 weeks
Driving Question & Anchoring Phenomenon	Earth's formation and the origin of all matter. *Where does Earth's matter come from and what is it made of?*	An outbreak of Sea Star Wasting disease along the West Coast of the U.S. that became the largest recorded marine mortality event. *-What is causing changes in Sea Star Wasting Disease?* *-How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?* *-What can we predict about the future of the species, given warming trends in sea surface temperatures?*	The increasing rates of infectious diseases and the emergence of new infectious diseases over the past 70 years. *Is climate change increasing infectious disease outbreaks?*
Investigative Phenomena	Origins of the Universe and Chemical Elements Atomic Models	Sea Star Wasting Disease Taxonomy & Phylogenetic Trees	Infectious Disease Outbreaks Infectious Disease Outbreaks & Climate Change

	Stars & Elements Planet Formation	Sea Star Morphology, Life Cycle, & Evolutionary History Genetic Mutations, Allele Frequency, & Natural Selection Geospatial Models & Data Representations Macroevolutionary Processes of Adaptation, Speciation, & Extinction Computational Models of Evolutionary & Ecological Dynamics Geospatial Models as Predictive Tools Mitigating Climate Change Impacts	
Interdisciplinary PBL Student Project (Science & Humanities	**Historically-relevant Chemical Elements** This interdisciplinary project investigates: *How can we use the geological distribution of elements and resources to understand the development of different human civilizations?* Using Taleblazer, a location-based augmented reality game platform, students work in	**Wasting Away from Climate Change: Evolution of Purple Sea Stars in a Warming Climate** This interdisciplinary project investigates the questions: *How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?* and *What can we predict about the*	**Avian Flu Case Study** An optional case study poses the driving question: *Will deadly bird flu strains become more common with climate change?* Students take on authentic project roles (e.g., epidemiologist, virologist, health and safety engineer, and information scientist) to interact with, analyze, and represent data

	teams to develop a game featuring a historically-relevant chemical element or compound. Student groups produce brief videos about the element's historical significance. Individually, students also complete an atomic analysis of an element in chemistry class and write a research paper in their humanities class.	*future of the species, given warming trends in sea surface temperatures?* Students work in groups, taking on authentic project roles (e.g., geneticist, ecologist, geographer, epidemiologist, population biologist, and social scientist), to create an infographic that includes a geospatial model, line graph, conceptual diagram, a prediction, and recommended action steps.	from a live tracking flu website and to develop a conceptual (causal-loop) model of factors that influence flu outbreaks.
Summative Assessment	Two written summative assessments are administered during this extended unit: **Origin of Earth's Matter** Students are challenged to construct an explanatory model for the origin and nature of Earth's matter. **Transformation of Matter During Early Earth's Processes** Students are challenged to construct a conceptual model representing an important chemical reaction within early Earth's processes.	**Beetles & Pines Scenario:** End-of-unit written assessment focuses on connections between mountain pine beetles, lodgepole pine trees, and warming temperatures due to climate change. Students are challenged to: construct a conceptual (causal-loop) model, examine maps and graphs, explain how the process of natural selection causes changes to species over time, and make a prediction about the process of natural selection as influenced by a specific environmental change over time.	**Lyme Disease Scenario:** End-of-unit written assessment presents Lyme disease as a specific case of an infectious disease being impacted by climate change. Students are challenged to: construct a conceptual (causal-loop) model, examine maps and graphs, and design protective measures to reduce human/tick interactions and the spread of disease.

Appendix C

Appendix C: *Ms. Cruz Case Study, Data Plan 2016-2018*		
Overarching Research Question: *What roles did a person positioned as a boundary spanner take on in a design-based RPP, and who benefited from her participation? How did she cross the boundaries of the respective institutions in the partnership and in what ways was she constrained in this work?* ***Analysis Plan:*** Content and discourse analysis through open coding for *in vivo* and *a priori* concepts of transcripts, field notes, memos, and other artifacts.		
Analytical Questions: ***How/Why?***	**Data Type:** ***What?*** **Data Source & Instrumentation:** ***How?*** **Time of Collection:** ***When?***	**Reasoning:** ***Why?***
What challenges or barriers did Ms. Cruz encounter when engaged in inter-institutional, cross-practice collaboration? *How did she express these boundaries, explicitly and implicitly?* *How did she (un)successfully navigate these?* *What boundary practices (tools and routines) developed during her instances of boundary crossing and negotiation?* *What was the role of hierarchy and power structures in*	**Key Data:** 5 Interviews with Ms. Cruz (video recordings, field notes, analytical memos) -Yr2 December 2016 -Yr3 September 2017, October 2017, March 2018, and August 2018 **Supporting Data:** 6 Classroom observations of co-teaching (field notes, video/audio recordings, analytical memos). November 2017 - January 2018 15 Debrief sessions (field notes, audio recordings, analytical memos). November 2017 – January 2018 Debrief spreadsheet (31 entries). November 2017 - January 2018 Collaborative CSP project planning meeting notes and critical email correspondences (weekly, over three years). 2015 - 2018.	To understand Ms. Cruz's evolving role and the boundaries she encountered. To understand how members of the CSP articulated project work and aligned their interactions, with a focus on Ms. Cruz's role. To identify boundary practices (routines and tools) Ms. Cruz may have employed to engage in boundary crossing. To uncover power structures and their impacts on Ms.

influencing her (in)ability to cross boundaries? *How was Ms. Cruz as the boundary spanner impacted by her participation in the design-RPP?* *What changes did she experience related to her professional learning, identity, agency, and interest?*		Cruz's (in)ability to cross boundaries. To build a thick description of Ms. Cruz based on her background, professional identity, and learning trajectory.

Appendix D

Appendix D: *Instances of Boundary Spanning*

Year & School Context	CSP Activities	Type of Boundaries Encountered	Ms. Cruz's Role in Negotiating Joint Work across Boundaries	Ms. Cruz's CSP Role at the time	Outcomes of Boundary Spanning Moves
Year 1 **STEM Academy**	Partnership formation activities/partnering processes.	*Institutional differences between Partner-Partner* -Sociocultural differences of partners. -Developing our partnering practices.	Institutional and insider knowledge of STEM Academy and district.	Teacher/designer	CSP partnership formed (vision, approach, membership). Her evolving definition of collaboration.
Year 1-2 **STEM Academy**	Curriculum design activities (chem and bio).	*Institutional differences between district, school, and university*	Brought chemistry expertise and craft knowledge to Ms. Eider and Mr. Sherman during design (professional expertise). Brought insider knowledge from school and district roles, including changing district mandates.	Teacher/designer and then transitioned to Project Manager/Instructional Coach (PM/Coach).	Design of three curriculum units that met STEM Academy's needs in balance with being able to go to scale.

Year 3 **Cascade STEM School (merged)**	Continuation of project activities in midst of school merger.	*Institutional differences due to school merger* -CSP researchers do not have existing relationships with school administration. -School administration is inaccessible to Ms. Cruz at first. - Layers of District mandates (adoption of common curriculum, shifts in PBL approach, etc.).	Communication liaison. Developed her own goals and adapted them when needed. Sustained CSP work in new school context. Received support and advice from her supervisor until he resigned. Leveraged her insider knowledge and influence from participation on district committees.	PM/Coach	CSP project work was able to continue despite major shifts in school (location, admin, teachers, students, etc.). CSP designers had to continually pivot to follow the district's changing mandates.
Year 3 **Cascade STEM School (merged)**	Continuation of project activities in midst of school merger.	*Professional and Sociocultural differences between teachers from the two schools brought together by the merger* -Ms. Cruz does not have prior relationship with new-to-her teachers.	Conducted needs assessments and relationship building strategies with new-to-her teachers. Continued to focus on Ms. Ly and supported all	PM/Coach	Ms. Cruz carried out her work, including her Tech Foundation responsibilities, and adapted as necessary in the face of the disruption of the merger.

		-Many teachers do not have experience with PBL and NGSS.	science and math teachers. Adapted her coaching practice due to needs assessment. Engaged in project planning, developed tools like PBL Framework, and created teacher working group for STEM Symposium.		
Year 3 **Cascade STEM School (merged)**	Bio units enactments. Research activities.	*Professional and Sociocultural differences between Researchers-Teacher* -Novice teacher enacting the curriculum units. -Boundary between researchers and Ms. Ly.	Co-teaching: classroom management. Nurtured coaching relationship with Ms. Ly. Shared craft knowledge with Ms. Ly. Supported Ms. Ly as a novice teacher. Suggested debrief spreadsheet and helped to employ	PM/Coach -Co-planning -Co-teaching -Co-debriefing	Evidence of boundary spanning by Ms. Cruz between teachers and researchers. Development of boundary practices: co-teaching, co-planning, de-briefing. Tensions emerged around differences in vision and approaches between Ms. Cruz, Ms. Ly, and researchers.

			this tool for data collection. Supported researchers data collection efforts (i.e., scheduling, recording data in debrief spreadsheet, etc.).		
Upon Reflection at end of Year 3 **Cascade STEM School (merged)**	Research activities across all three years of CSP.	*Sociocultural differences between Researchers – Practitioner* -Ms. Cruz participated in weekly meetings as a regular boundary spanning practice. -Meetings served both project coordination and research purposes. -Researchers frequently shared research updates and discussed issues related to data collection, analysis, and presentations.	Developing shared knowledge and language with researchers (incidences in which a new term or idea is introduced by researchers or Ms. Cruz) -Attended weekly meetings. -Provided updates from district, school, or partner teachers. -Contributed to shared collaborative meeting notes.	PM/Coach	*Mostly impermeable* Research side of the project was an impermeable boundary that Ms. Cruz found to be opaque. Evidence of her learning and engagement in research activities. Role may have been more permeable than she realized. Power dynamics when working with researchers and PI.

Appendix E

Appendix E: *Boundary Negotiation Practices After the School Merger*

Identified Boundary	Boundary Practices and Objects Ms. Cruz Used to Support Joint Work
Institutional differences between the district and the school The district issued layers of mandates that STEM Academy had been immune to in its former state before the school merger.	• Leveraged her insider knowledge and influence from participation on two district-level committees. • Communicated shifting district mandates to the CSP researchers, including sharing district documents, to enable the team to be nimble during curriculum design. • Encouraged science teachers to find way to flex during the design of interdisciplinary PBL projects, understanding that math and humanities teachers needed to adhere to a common curriculum with fidelity.
Institutional differences between Ms. Cruz and the new administration team The new leadership team was inaccessible to her as the new school launched.	• Even though she could not meet with the school administrators, she proceeded to develop her own goals to guide her work. • Her supervisor at the foundation provided her with support, advice, and advocacy until he resigned from his position. • She sought out advice, support, and learning opportunities from CSP researchers.
Professional differences among teachers Differences in professional expertise and work practices among teachers from both schools and newly hired teachers.	• Conducted a needs assessment with teachers. As a result of needs assessment, adapted her coaching practice to focus on NGSS and PBL and began engaging in co-planning with teachers. • Worked to build relationships with all science and math teachers. • Boundary object: NGSS and curriculum planning tools (e.g., Buck Institute Project Planning Guide, storylining template, her own PBL Framework). • Shared her old physics course materials with new physics teachers. • Invited CSP researchers to present a training session at Tech Foundation's summer institute to help prepare new teachers. • Created a working group of teachers that would help her disseminate information about the STEM Symposium. • Developed a project spreadsheet to help all teachers track their students' STEM Symposium projects.

Sociocultural differences between teachers and students Teachers needed to build relationships with new-to-them students.	• Employed a motto of "love kids first" by building relationships and acknowledging the "tiny transformations" that occurred with former Cascade School students as they encountered a new way of learning. • Used school celebrations and competitions as ways of highlighting former Cascade School students rather than focusing solely on former STEM Academy students.
Sociocultural differences between students Cultural divide between former Cascade School and former STEM Academy students.	• At the beginning of the school year, teachers across the school engaged in activities specific to building a shared school culture. • PBL pedagogy engaged students in group work for extended periods of time. Teachers and Ms. Cruz met during planning periods to share their knowledge of different students to configure groups that brought together students from both schools into collaborations. • STEM Symposium became a shared experience among all students.

Appendix F

Original draft of the Project Team Contract:

PROJECT TEAM CONTRACT	
Project Name:	
Team Members (roles):	

Our Agreement

- We will be present and listen to each other's ideas with respect.
- We will do our work as best we can.
- We will do our work on time.
- We will ask for help if we need it.
- We will ______________________________________.
- We will ______________________________________.
- We will ______________________________________.
- We will ______________________________________.
- We will ______________________________________.

If someone on your team is not upholding the terms of the contract the team may hold a meeting and ask the person to follow our agreement. If the person still breaks the rules, we will ask our teacher to help find a solution.
If someone on our team breaks one or more of our rules and does not contribute to the group project, the team may have a meeting and ask the person to follow our agreement. If the person still breaks the rules, we will decide as a team to vote out that member.

Date: ____.

Team Member Signature:

Contract Terms	**What it looks like**	**Who violated this term? When?**	**Interventions** (what have your group done to improve the situation?)	**Strikes (#)**
Being present	- I will not miss more than____class periods. - I will not be tardy for more than _______times.			
Technology Usage	- I will use technology (phone, tablet, laptop, etc.,) only for educational purposes. - I will listen to music only when it is individual work time.			
Productivity	- I will meet all of the assigned deadlines - I will produce high quality work to the best of my ability			
Collaboration				
Professionalism				

Ms. Ly's revised version of the Project Team Contract:

PROJECT TEAM CONTRACT	
Project Name:	**SSWD Exhibition**
Team Members (roles):	

Our Agreement

- We will listen respectfully while others are talking.
- We will respect others opinions.
- We will complete assigned work on time.
- We will ask for help when needed and help others.
- We will stay on task.
- We will use only credible sources.
- We will not misuse technology.
- We will try our best.
- We will distribute work evenly.

If someone on our team is not upholding the terms of the contract and does not contribute to the group project, the team may have a meeting and ask the person to follow our agreement. If the person still breaks the rules, we will ask our teacher to help find a solution.

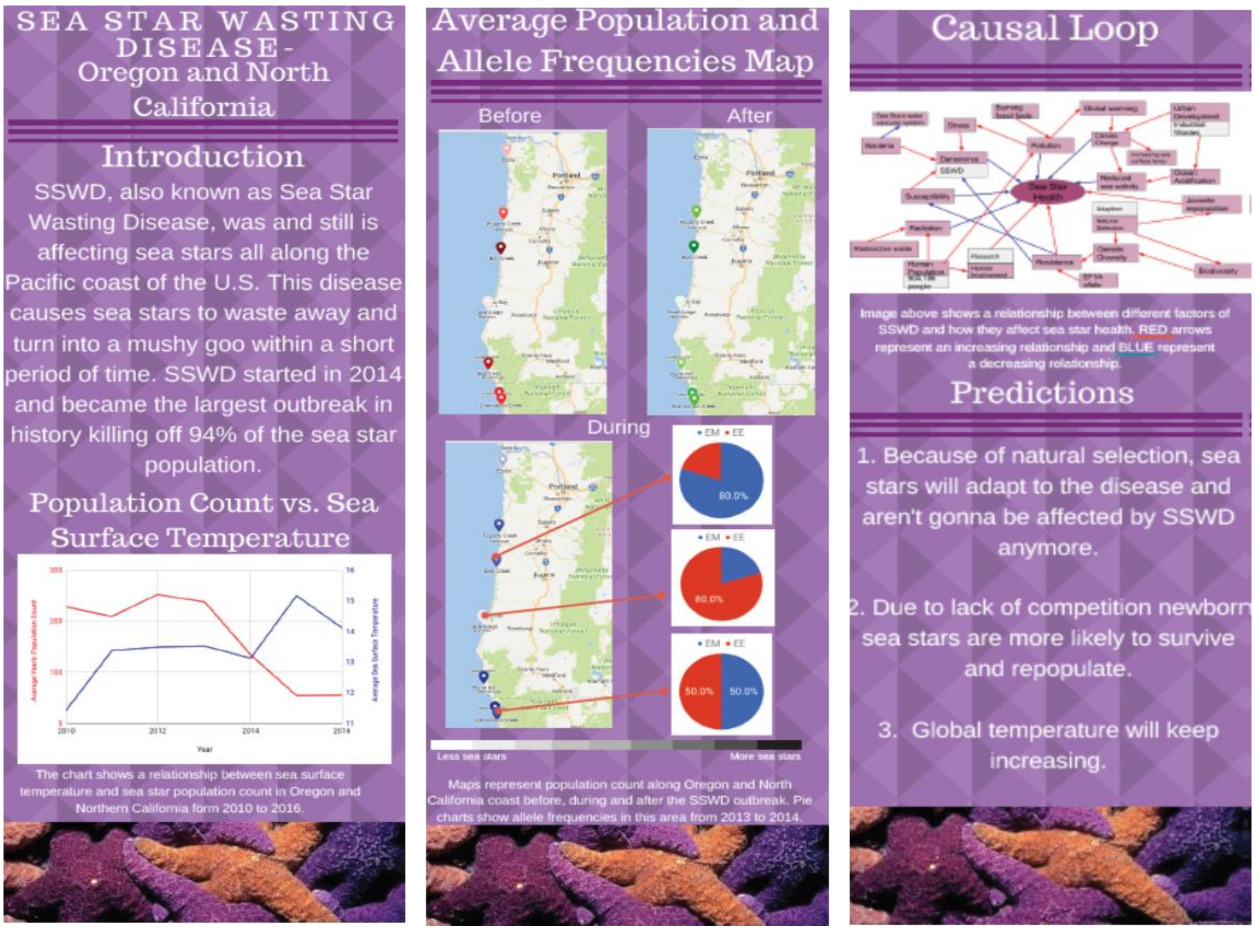
Date: ____.

Team Member Signature:

Appendix G

Driving Questions for the Biology Evolution Unit

- What is causing changes in Sea Star Wasting Disease?
- How has Sea Star Wasting Disease affected geographic sub-populations of purple sea stars in different ways?
- What can we predict about the future of the species, given warming trends in sea surface temperatures?

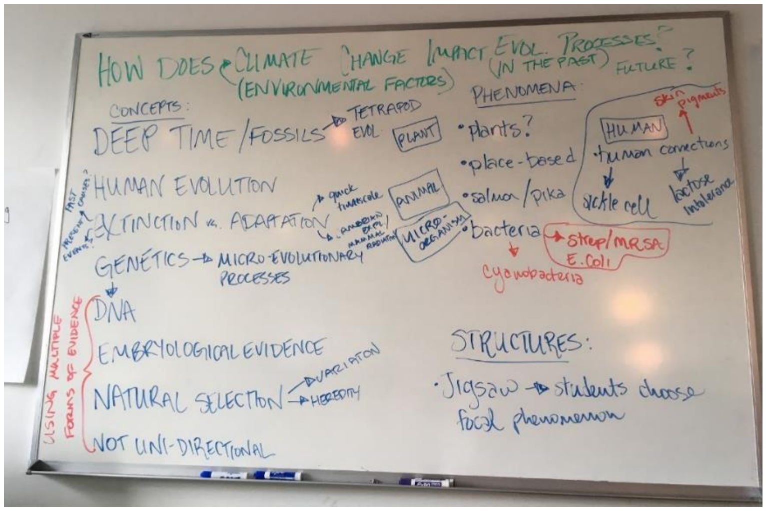


Appendix G. This example from a group of students in Ms. Ly's class shows one team's collaborative infographic, a part of their project for the biology evolution unit. It integrates their analysis of large data sets from the perspective of an Oceanographer, Population Biologist, Epidemiologist, Geneticist, and Social Scientist in order to answer the unit's driving questions.

Appendix H

Appendix H. A design artifact from the first design session of the CSP partnership in which STEM Academy teachers and researchers collaborated to develop a causal loop model for climate change.

Appendix I



Appendix I. A design artifact from the first design session with two collaborating biology teachers external to the CSP that shows whiteboard brainstorming of concepts, phenomena, and pedagogical structures.

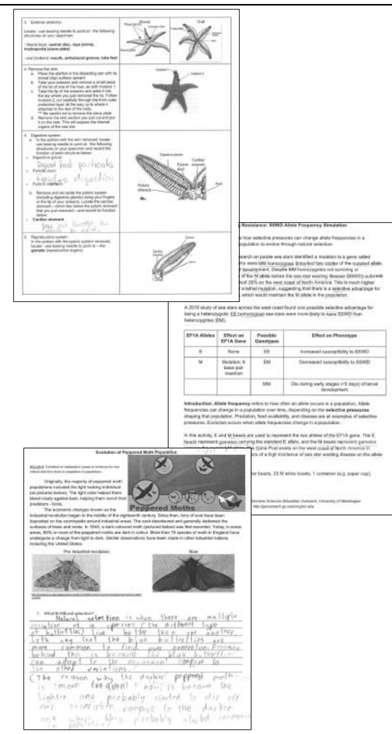
Appendix J

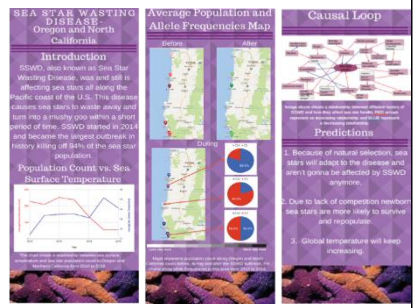
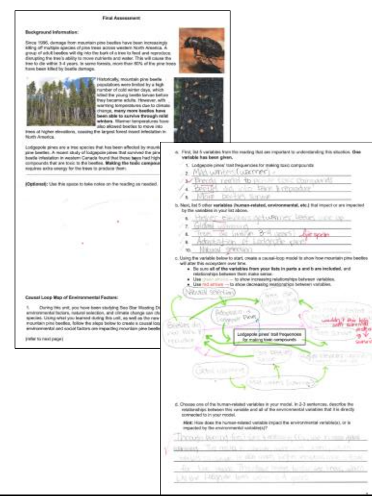
Phenomena & Driving Question	Investigation We Engage In To Make Sense of Phenomena—Using the Science & Engineering Practices (specifically Computational Thinking & Equity Strategies)	Personal or Cultural Relevance or Community Interest or Need	What We Figure Out (DCI & CCC Components Learned)	Formative Assessment Activities & Next Steps
Overarching Driving Question: How have environmental factors impacted the evolution of species in the past? How will climate change impact the future of species' evolutionary trajectories?				
Lesson 1: What is evolution? (1-2 days) **3D Learning Performance:** Elicit students' initial understandings of evolutionary processes and build a conceptual foundation, especially of the different timescales that evolution can operate on, for the rest of the unit.				
Phenomena: Tetrapod evolution - comparative anatomy and common ancestry Antibiotic resistance **Project Connection:** Introducing the similarity in tetrapod anatomy as puzzling phenomena	**Cascade of Practices:** Students construct explanations to explain their initial understandings about evolutionary processes, especially through the comparative case of tetrapods' forelimbs.	Discussion of social vs. scientific controversy • Unpacking scientific meaning of "theory" → bridge to everyday understandings • Resource: teaching about controversial topics Different ways to conceptualize deep time: • Human arm • Clock metaphor • Classroom (can just use list at end)	**Unpacked DCI Components:** LS4.A: Evidence of common ancestry: We can use multiple lines of evidence (morphological, genetic, embryological) to infer organisms' evolutionary history and patterns of relatedness. **Unpacked CCC Components:** Patterns: We can observe evolution at different timescales (antibiotic vs. tetrapod evolution).	**Formative Assessment Activities:** Introduce Idea Journal or Initial Ideas worksheet; have students give initial ideas on tetrapod evolution.

Appendix J. A design artifact from co-design with two collaborating biology teachers shows use of rainbow storylining tool for unit design. Only the first lesson is shown in this Figure. [Punctuation maintained from original data source].

Appendix K

Appendix K: *Type of Scientific Phenomena for Curriculum Design*

Type of Scientific Phenomena for Curriculum Design	**Example from SSWD Unit**	**Examples of Curriculum Artifacts and Student Work**
Anchoring Phenomenon *Unit-level*	**Anchoring phenomenon:** A disease outbreak affecting sea stars along the West Coast of the U.S. that began in 2013. **Driving question:** What is causing changes in Sea Star Wasting Disease?	
Investigative Phenomena *Lesson-level*	Through their engagement in scientific practices, students made sense of different investigative phenomena, which build towards their understanding of the anchoring phenomenon. Example driving questions: **Evolution and natural selection:** How do changing environmental conditions lead to adaptation, speciation, or extinction of species and sub-populations of species? **Climate change:** How can environmental policies and community actions help to mitigate the impacts of climate change and take into consideration the needs of multiple stakeholders (human and non-human)? **Sea stars and SSWD:** What factors have influenced differences between sea stars and populations? How can we characterize those differences as they relate to SSWD?	Examples of curriculum artifacts include: Sea star dissection protocol, allele frequency lab, and peppered moth simulation.

Project Phenomenon *Project-level*	Students took on authentic scientific roles (Oceanographer, Geographer, Population Biologist, Geneticist, and Social Scientist) to work within teams focused on a specific geographic area. Students worked with publicly available scientific data (i.e., sea surface temperatures, sea star population counts). Teams collaborated to answer the questions: • *How has SSWD affected geographic subpopulations of purple sea stars in different ways?* • *What can we predict about the future of the species, given warming trends in sea surface temperatures?*	 Each team's infographic featured their analyses and visualizations of data, which included: geospatial map, line graph, pie charts of allele frequency predictions, causal-loop diagram, and predictions of the evolutionary future of purple sea stars.
Assessment Phenomenon *Summative/end-of-unit*	A new case study is introduced on the end-of-unit written exam. The case study features the connections between the mountain pine beetle, lodgepole pine trees, and warming temperatures due to climate change. Students are asked to engage in a variety of scientific and computational practices to explain how the process of natural selection causes changes in traits within populations of lodgepole pines over time.	

SSWD = Sea Star Wasting Disease