DEVELOPING TEACHER IDENTITY IN ELEMENTARY SCIENCE: A LONGITUDINAL STUDY ON THE INTERACTION BETWEEN STUDENT SENSEMAKING AND TEACHER IDENTITY

By

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ABSTRACT

Promoting relevant, meaningful, and equitable science teaching learning environments for both teachers and students has become a critical objective for science education. To achieve this goal, fostering students' sensemaking experiences in science becomes critical. Working towards such a committed, and equitable sensemaking environment is closely connected to the developing identity trajectory of the science teachers. Teachers prioritize certain conceptions, beliefs, and practices in their science classrooms based on their *personal prior experiences*, conceptions of science teaching and learning within the larger parts of their institutional system, and instructional choices, and eventually practices in teaching science. These practices and conceptions connect back to their ever changing historical, social, and cultural backgrounds and experiences; their interactions and relationships with their communities and institutions; and therefore, to their teacher identities.

Over the past decades, there has been robust research regarding teachers' identities, perceptions, and conceptions of teaching science. In addition, most research on science teacher identity has been on personal histories of teachers and how they shape and reveal certain science identities. This emphasis on personal stories reflects on individualistic view on science teacher identity and crafted by mainly utilizing data sources such as written or oral reflections and teacher interviews. Therefore, several scholars claimed that more research on the nature and characteristics of the contexts and systems are needed to understand the ways that identity is influenced by multiple histories of participation.

Considering there is still much to learn about how we can capture and interpret the meaning behind science teacher identity to make critical implications on teacher development and student sensemaking in science, this study has two main aims a) investigating the relationship (interaction) between teacher's changing practice and students' sensemaking experiences in learning and doing science, b) investigating an elementary teacher's developing identity to teach science considering her personal history and changing conceptions and practices on science teaching over years.

To do so, I conducted a single case study using longitudinal qualitative research (LQR). I specifically zoomed in on Ms. Spark's use of sensemaking practices while teaching 3rd grade science. Data sources include detailed observation field notes, individual interviews with Ms. Spark, and student work and artifacts over three years (between 2018 and 2023).

The findings present the journey of an experienced teacher, Ms. Spark, as she keeps developing a reform-based mindset in teaching elementary science using PBL-oriented curriculum materials and sensemaking practices. This study has important implications for teacher education, professional development, curriculum, and instruction.

The evidence indicates that sensemaking practices can be used as a tool and support for pre-service and in-service elementary teachers as they learn to teach science in a sensemaking, equity, and justice-oriented vision. The sensemaking practices provided a mindset and set of pedagogical guidelines for the teachers where they can leverage equity and justice-oriented, humanizing approaches to science teaching in defining, redefining, and implementing their teaching practices. In addition, this research contributes to our understanding of how a teacher's personal background and positionality, as well as their experiences with other collective and systemic structures (besides the university methods course), such as their current and future relationships with their field placements, school administrations, district leaders, curriculum coordinators, research partners, or their colleagues could help researchers to capture the complexity of developing teacher identity.

To my beloved mom and dad, Berrin and Tevfik; and to my lovely companion, Lokum

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TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION AND RATIONALE

Promoting inspiring, relevant, meaningful, and equitable science learning environments for both students and teachers has become one of the critical objectives for the science education community. To cultivate such learning environments, *sensemaking* has recently been stressed in number of influential policy documents and studied by many educational scholars and researchers in the context of science education (e.g., Berland & Reiser, 2009; NGSS, 2013; NRC, 2007; NRC, 2012; Schwarz et al., 2017).

Although researchers conceptualize sensemaking in different ways, they all share the perspectives from cognitive, constructive, and sociocultural theories of learning (Ford, 2012; Kapon & DiSessa, 2012; Lave & Wenger, 1991; Weick, 1995). Drawing on a sociocultural perspective of learning (Esmonde, 2016; Lave & Wenger, 1991), I investigate how to conceptualize and foster students' sensemaking experiences by proposing critical and relevant pedagogical and instructional practices in elementary science classrooms. To do so, I define sensemaking as an active, reciprocal, social-cultural, and process-based experience in which students not only reflect on identifying the phenomena but figure out why and how phenomena happen and work by resolving an uncertainty that they engage with (Manz & Suárez, 2018). Therefore, I refer to sensemaking as a holistic and collective set of learning experiences that occurs by implementation of certain practices both in formal and informal learning and teaching settings to promote students' figuring out experiences in science phenomena. Most importantly, I argue that sensemaking experiences cultivate reciprocal and collective learning opportunities (more than an individual) for students to socially and emotionally connect to others, build relationships with one another, and share experiences by building on their backgrounds to engage in science learning. In that way, students can have a chance to set their individual and collective learning goals, develop ownership and science identities, and establish critical consciousness while maintaining reciprocal and positive relationships in their learning communities (Berland et al., 2016; Condliffe et al., 2017; Muñiz, 2020)

That is why it has utmost importance for younger students to engage with and make sense of science phenomena especially in elementary science settings (Odden & Russ, 2018; Zangori et al., 2017). Elementary students should have foundation to co-construct knowledge which anchors development of disciplinary knowledge that will serve as the foundation for more complex understanding in their later ages (Zangori et al., 2013). Without sensemaking experiences, there

is no driving force for students to a) relate, wonder, and make connections with the world around them, b) take a step further by experiencing the phenomenon to figure out how and why it happens, c) be critical consumers and developers of meaningful and foundational knowledge, and d) develop critical consciousness and perspective to make societal changes. In other words, if we don't help children to wonder and ask questions about science by giving them an opportunity to bring and connect their unique experiences to science, they will have a challenging time figuring out and explaining important phenomena and building new understanding of critical ideas (Lowell et al., 2021; Schwarz et al., 2021). Therefore, science educators and researchers need to create a science learning environments (starting from elementary level) where students can bring their own expertise and resources to the learning process, consider different communities and societies' realities, and needs, and make sense of the phenomenon within an equitable learning environment (Bang et al., 2012; Nasir et al., 2006).

Working towards such committed, consistent, and critical equitable sensemaking environments for elementary students is also closely connected to the changing and developing identity trajectory of science teachers. Teachers prioritize certain conceptions, beliefs, and practices in their science classrooms based on their *self*, priorities, instructional choices and eventually practices. These practices and conceptions connect back to their everchanging historical, social, and cultural backgrounds and experiences; their interactions and relationships with their communities and institutions; and therefore, to their professional teacher identities (Avraamidou, 2016; Luehmann, 2016; Mensah, 2016; Pellikka et al., 2022). To gain a deeper understanding on how science teachers choose to teach the way they do, and how their individual and collective pedagogical, and instructional choices (such as their practices) navigate certain aspects of their teaching, it is critical to investigate the change in teacher identities over a period of time (Carlone et al., 2015; Carlone & Johnson, 2007).

Over the past decades, there has been robust research regarding teachers' identities, perceptions, and conceptions of teaching science (e.g., BouJaoude, 2000; Crawford & Cullin, 2004; McDonald & Songer, 2008; Taylor & Booth, 2015). In addition, most research on science teacher identity has been on personal histories of teachers and how they shape and reveal certain science identities. This emphasis on personal stories reflects on individualistic view on science teacher identity and crafted by mainly utilizing data sources such as written or oral reflections and teacher interviews. Therefore, several scholars (e.g., Avraamidou, 2016; Carlone et al.,

2014) claimed that more research on the nature and characteristics of the contexts and the ways' identity is influenced by multiple histories of participation is needed. In other words, a need for studying how teachers' identities cannot be examined separately from the multiple and collective stakeholders from the micro- (i.e., individual), meso- (i.e., classroom), and macro- (i.e., society) levels in which they operate over time (Carlone, 2022; Carlone et al., 2007).

Besides the growing literature on teacher identity work, most of the empirical research on sensemaking investigates students' sensemaking experiences based on their meaningful involvement with the scientific practices and explanations without necessarily bringing an explicit equity and justice focus (e.g., Benedict-Chambers et al., 2017; Berland et al., 2016; Berland & Reiser, 2009; Zangori et. al., 2017) or focuses on the processes teachers use to make sense of the use of epistemic tools (e.g., Sezen-Barrie et al., 2019). Most importantly, researchers conducted most of the empirical studies from the secondary to tertiary level (e.g., Lowell et al., 2021; Odden, 2021).

Considering there is still much to learn about how we can capture and interpret the meaning behind science teacher identity to make critical implications on teacher development and student sensemaking in science, this study has two main aims. First, I will investigate the relationship (interaction) between teacher's changing practice and students' sensemaking experiences in learning and doing science. Second, I plan to investigate an elementary teacher's developing identity to teach science considering her personal history and changing conceptions and practices on science teaching over years. To do so, I draw from various sociocultural perspectives on identity and learning, then propose a model to capture developing teacher identity considering three critical components: a) teacher's personal background, history and positioning; b) teacher's conceptions of science learning and teaching through their belief and value systems which shapes through the social, cultural and political context and community in which they belong, c) teacher's implementation of practices (six equitable sensemaking practices that I propose) to support their students' meaning-making experiences in elementary science classroom.

Research Questions

In line with the goals and proposed framework of this study, I raise three main research questions:

1. How does an elementary teacher's implementation of practices (sensemaking practices) change over years?
2. How does the change in the teacher's implementation of practices support students' sensemaking experiences?
3. How does individual, collective, and practice-level experiences of the elementary teacher become a critical tool to capture and interpret their changing identity trajectory in teaching science?

Addressing these critical research questions bring critical and meaningful contributions for teacher educators, practitioners, curriculum developers, as well as the researchers of science education who studies students sensemaking and teacher identity. More specifically, I argue that this work will significantly add to the theoretical and empirical literature of teacher identity work in science education. First, this study tackles the question of studying an elementary teacher's identity within an in-depth and longitudinal approach. Since longitudinal studies are considered time-consuming, expensive, and difficult to complete because of the difficulty of finding and/or following up with past research participants, there is a lack of longitudinal studies and they are even more needed as the "next step" in identity research (Butterfield & Marshall, 2022; Dixon, Harris & Ballard, 2022). Therefore, this study will fill the gap by bringing empirically rich and longitudinal single case study. Additionally, this study also brings a novel approach studying teacher identity by integrating individual, collective and practice-oriented sociocultural constructs.

In addition, this work adds to our knowledge on elementary students' sensemaking in science by centering sensemaking practices and amplifying the equity and justice-oriented approach for the practice. It can help researchers and practitioners understand how sensemaking and justice-oriented science learning environments need to be taken and work together by the implementation of sensemaking practices. Most importantly, a longitudinal approach will help to see how sensemaking practices develops in teachers and students. In other words, this work illustrates how elementary teachers develop a sensemaking and justice-oriented mindsets and critical teacher identities by implementing practices and develop conceptions over time. Another valuable aspect of this study provides empirical evidence on how a teacher can engaging with, adapt and implement curriculum documents beyond its provided version. It can contribute to curriculum studies by bringing examples of unexpected and reform-based enactments from

teachers to support students' equitable sensemaking experiences in science. More specifically, sensemaking practices and curriculum implementations can act as a tool for teacher educators which can incorporated into methods courses, field experiences, and even as part of professional development efforts.

CHAPTER 2: THEORETICAL BACKGROUND AND FRAMEWORK

Capturing Developing Teacher Identity Within the Identities-In-Practice Lens

Teacher identity has been defined and studied in a variety of different ways (Avraamidou, 2020, Beauchamp & Thomas, 2009; Calabrese Barton et al., 2013; Carlone & Johnson, 2007; Luehmann, 2016; Mensah, 2016; Pellikka et al., 2022). From a sociocultural perspective, teacher identity has acted as a tool to mediate aspects of human development and framed as a significant way to understand the reasoning behind the changes in teacher learning and practice (Carlone et al., 2014; Holland et al., 1998; Lave & Wenger, 1991; Nasir & Cooks, 2009). For teacher educators who aims to help foster the professional growth of elementary teachers to teach science, it has utmost importance to understand how elementary teachers' personal and community-oriented conceptions and implementations of science teaching practices develop and change over time. Therefore, I position teacher identity as an indicator of transformative agency to understand the role of teachers' individual and collective experiences, values, and beliefs in learning and teaching settings (Dixon et al., 2022; Holland & Lave, 2001). Identity studies are also imperative to understand the social, cultural, and institutional actors that play a role in teachers' intellectual growth to be able to discover the new ways of organizing learning, provide reform-oriented resources for them, and ensure equitable science learning experiences for students.

In line with that positioning, this study draws from various socio-cultural theoretical framings on teacher identity work. To address how teachers develop teacher identity and position themselves in relation to science teaching in the authentic teaching settings, I mainly draw on Holland and colleagues' (1998) theory of ***identity-in-practice***. This framing positions teaching and learning as a fluid, dynamic and ongoing process: "persons taking form in the flow of historically, socially, culturally, and materially shaped lives" (Holland et al., 1998, p. 5). To investigate how identities are developed through these actions and how those actions gain meaning by other members of the community, Holland et al. (1998) identified four features of a figured world within the lens of identity-in-practice: culture, community, artifacts, and power and privilege. These four components of the framework –culture, community, artifact, and power – takes into consideration of teacher's perceptions and actions, positioning, as well as their agency as the base for the identity development (Carlone et al., 2014).

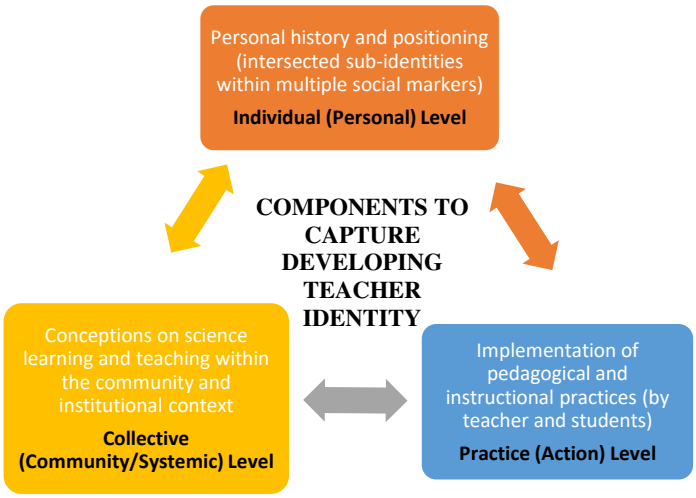
Aligning with the ***identity-in-practice*** theory, Nasir and Cooks' (2009) theory of ***practice-linked identities*** also considers the influences of psychological and sociological accounts on identity capital. These accounts focus on the question of how individuals can negotiate life passages in an increasingly individualistic, complex, and chaotic world; and offer a conceptual and comprehensive tool to enrich our understanding on what kind of available and accessible resources (beyond just material ones) impact the process of constructing multiple identities. In addition, Cote and Levine's (2002) **cultural-identity model** also inspires the framework of this study, since it considers three levels of analysis in identity development: individual, social interaction, and broader society. These frameworks addressed how physical learning and teaching environments, organizational systemic structure of the teaching event, and how the discourse and social interactions we have shape our negotiations and transformations in the learning and teaching process (Luehman, 2016).

Considering their overlaps and affordances to explore teacher identity, I argue that these frameworks guide us on how to capture teachers and students' authentic teaching and learning experiences since they prioritize teacher's development of sense of agency, belonging in their communities, and their process of gaining reform-based vision in teaching and learning. Additionally, there are several critical reasons for me to draw from these sociocultural and practice-oriented identity theories in this study. First, they both value the teacher's developing agency and actions as the critical components in the development and refinement of science teacher identity. These theories do not only focus on teacher's historical background, conceptions, and prior experiences from an individual perspective, but they also center teacher's actions and practices which have collective and systemic outcomes for their identity development, as well as for students learning experiences. In other words, these theories also prioritize teacher's actions as an outlet that may shape how the teacher implement different pedagogical practices, and how they develop reform-based conceptions in their teacher identity throughout their career. Additionally, these actions also can shape students' learning experiences by impacting how students can access to a certain level of cognitive, social, cultural, emotional, or affective support. Second, considering teachers constantly engage with "identities-in-practice" as they learn to teach and then teach to their own students during their professional careers, these theories offers ways of exploring the multiple ways of how teachers position themselves towards science and teaching science, as well as how they are positioned and perceived by multiple

stakeholders in the community they live in and teach (Gee, 2017; Holland & Lave, 2001; Mensah, 2016).

Therefore, I propose a model to capture developing teacher identity drawing on these relevant theories on identity work (see Figure 1). Building on them, I propose three components to represent individual and collective perspectives on teacher identity. Apart from them, I bring a specific and central focus on the types of pedagogical and instructional practices that an elementary teacher chooses to use and implement in teaching science. This particular and explicit focus on *practice* in this framework can make a unique contribution to the field. The model prioritizes and centers teachers' (and therefore students) authentic actions (pedagogical and instructional practices) based on their conceptions, beliefs and values in science teaching and learning. Even through practices take place in several identity theories, more empirical, real-time, and longitudinal classroom investigations are needed in identity research. Therefore, identity researchers and teacher educators can use this framework as to a tool to explore the role and importance of the actual classroom implementations in the identity development process. In addition, these three components cannot be considered separately, rather they are closely connected to each other, inform each other, and shape one another. For example, the individual social and cultural markers that the teacher possess strongly shapes their conceptions and implementations of science teaching by how to interact and communicate with the people around them, as well as how to negotiate, relate and transform the practices they choose to enact in their own classrooms.

Figure 1. Individual, Collective, and Practice-level Components to Capture Developing Science Teacher Identity



More specifically, this framework will serve as an analytical lens to explore an elementary teacher's developing identity to teach science over time by addressing the changing patterns in three critical components: a) teacher's personal history and positioning; b) teacher's conceptions of science learning and teaching through their belief and value systems which is shaped through the social, cultural, and political context and community in which they belong, c) teacher's implementation of practices (equitable sensemaking practices for this study) to support their students' meaning-making experiences in elementary science classroom (Carlone et al., 2015; Rahm & Moore, 2016; Søndergaard, 2005). As a first component, the teacher's unique *self* as an individual is critical to start exploring the developing identity trajectory. Considering their own personal histories, backgrounds, and positionalities in their own community and teaching space is essential and inevitable to understand the entire process and experience of their identity development. The second component emphasizes the teacher's evolving conceptions of science learning and teaching which develops through their interactions and relationships with the collective context, community stakeholders, and institutions. Finally, the real-time classroom practices constitute the practices that teachers choose to implement for supporting their students' learning experiences and enriching their own teaching experiences which becomes the complementary aspect of this identity development framework.

Overall, this framework for my analysis will provide an outlet and perspective to identify and interpret teacher's transformational process in teaching science, by highlighting how teachers are socially recognized, how they develop certain conceptions and practices towards teaching science, and how they interpret, re-interpret, and negotiate these changing experiences and conceptions to teach young children science in an everchanging and complex contexts. Following, I will delve into each of the components of the proposed identity framework by providing further definitions and explanations to my thinking.

Personal history and positioning: Individual level

I refer to personal background and positioning as a form of personal and positional identity that develops through one's multiple and intersected social markers (sub-identities)- ethnicity, economic status, race, religion, age, gender and so on (Chen & Mensah, 2018; Crenshaw, 1989). These markers are essential to figure out how teachers can position their own "self" in a particular community setting and to investigate the interplay between these social and cultural markers in shaping their teacher identity. Therefore, personal, and positional identity can

help to capture teachers' unique individual experiences and interactions between their growing sub-identities. For example, previous research on positional identity shows that secondary and elementary pre-service teachers of color's multiple personal identities such as their racial, gender, and ethnic backgrounds intersect with each other. These multiple personal sub-identities shape their interactions, expressions, negotiations, and their relationships with both their students and science (Avraamidou, 2020; Mensah, 2016; Richmond, 2016). In that way, personal identity connects closely to power, especially in relation to one's social location and relevant communities' histories of practice (Carlone, 2022). Therefore, teachers' personal histories represent one of the components of the developing teaching identity, as it becomes the starting and growing point to form meaningful conceptions on science teaching and learning and build a critical and relevant pedagogical and instructional repertoire of practices (Avraamidou, 2016; Calabrese Barton et al., 2020; Nasir & Cooks, 2009). In that way, this component captures the connection between the socially constructed, individual nature of identity by illustrating the interplay between *self* and social and institutional power structures in the teaching context (Calabrese Barton et. al., 2020; Carlone, 2022; Holland et al.,1998).

Conception of science learning and teaching: Collective level

Over the last decades, teacher education research has conducted a substantial amount of research on the complex relationships between teacher values, beliefs, and practices (e.g., Cheng et al., 2021; Clark & Peterson, 1986; Fang, 1996; Gess-Newsome et al., 2003; Idsardi et al., 2023). As a newer line of research, several scholars study science teacher identity by focusing on the conceptualization of professional identity (e.g., Akerson at al., 2016; Lai & Jin, 2021; Richmond, 2016) by discussing science teachers' conceptualization of professional identity. While Akerson and colleagues (2016) suggest that elementary teachers' (who teaches science) identities cannot be developed without developing an understanding of what constitutes science (such as the nature of science); Beijaard, Meijer, and Verloop's (2004) account of professional identity unpacks how contextual factors, such as teacher's relationships with the family, colleagues, and institutions can shape their professional identity and ongoing meaning-making and interpretation processes in identity development. Moreover, the evidence from the literature addresses the reciprocal and meaningful relationship between teachers' conceptions and their practices at the K-12 level (e.g., Buehl & Beck, 2014; Lui & Bonner, 2016; Wilkins, 2008). Therefore, this component of teacher identity aims to consider a) how teacher's conceptions of

science teaching inform the implementation of reform-based practices and curriculums, and b) how the personal and contextual factors inform those reform-based practices as it shapes teacher identity.

More specifically, conceptions inform and are informed by personal and institutional factors and contextual factors (Idsardi et al., 2023). As I suggested before, personal histories include teachers' historical and social background, and their prior professional and life experiences (such as extent of teacher education). Drawing from these prior experiences, teacher's conceptions on science teaching and learning is shaped by personal and institutional community contexts. In other words, teachers' self-reflection, and self-interpretation on what counts as an ideal science teaching and learning space develops through the contextual collective factors. For example, teacher's relationships with their school administrations, curriculum coordinators, research partners through professional development sessions, students' families and parents, and their colleagues (fellow teachers) impact how they interpret and reinterpret what values and priorities they hold in science teaching and learning environment .All these larger systemic community context play a crucial role in teacher's conceptions when they develop certain beliefs, values, and visions on what counts on ideal science learning and teaching.

Therefore, I define *teacher conception* as the set of beliefs and values that the teacher holds about an ideal science learning and teaching environment through their a) perceived role of the teacher and student in learning environment, b) ideas and stance on the pedagogical and instructional strategies to be implemented, c) perception and ideas about the content on the curriculum materials that are enacted, and d) experiences about the school and schooling through the relationships with the families, colleagues, administration, and professional learning opportunities.

Implementation of pedagogical and instructional practices: Practice Level

Focusing on the teacher's pedagogical and instructional practices and how students engage with and respond to them is critical for this study to a) theorize how and why the implementation of practices becomes critical to capture and interpret the changing teacher identity, and b) how and why implementing these practices may promote elementary students' sensemaking experiences in science.

Therefore, practice level experiences become the core component of this framework to understand how identity is, in part, recognized and developed through the actions in which

teacher and students choose to engage. By participating in certain activities and practices, teachers and students may come to see how their roles start to shift in their teaching and learning trajectories. Therefore, implementing practice guides a teacher to assign meaning to those practices based on their values and the demands of the society pose which may in turn change their own beliefs and values toward learning and teaching. Therefore, this component makes the core of the "identity-in-practice" aligned approach and framework to identity (Carlone et al., 2014).

Considering the importance of implementing reform-based practices in teaching science, I propose *sensemaking practices* as the core practices of this study for teachers and students to use. In other words, I argue that everyday instructional practices produce shared meanings that impact teacher identity work. Therefore, I investigate an elementary teacher's implementation of *sensemaking practices* over years in the effort of cultivating her students' sensemaking experiences in elementary science. Following, I further explain a) my definition of sensemaking in the context of elementary science education, b) six core sensemaking practices as a way to foster students' sensemaking experiences in science.

Sensemaking Practices to Foster Equitable Sensemaking Experiences

I propose six sensemaking practices to a) help teachers to develop reform-based science teaching mindset and identities, and b) provide teachers a guideline to support their students to have critical, equitable, justice oriented, and relevant sensemaking experiences in learning science. Following, I will initially unpack how sensemaking is characterized in elementary science settings. Then, I will address why sensemaking experiences are critical to cultivate in elementary classroom settings. Finally, I will introduce my own definition and interpretation on sensemaking by defining six sensemaking practices that an elementary teacher implements over three-year period in her third-grade science classrooms.

Science education researchers have increasingly studied sensemaking in science classrooms and proposed several definitions to what counts as sensemaking in science classrooms (e.g., Berland & Reiser, 2009; Fitzgerald & Palincsar, 2019; Odden & Russ, 2018). The literature highlights the link between explanation, dialogical reasoning, and use of evidence as the prominent aspects of scientific sensemaking (Flood et al., 2015; Ford, 2012; Odden & Russ, 2018). Therefore, sensemaking in science is mostly characterized based on fundamental epistemological assumptions about the validity of evidence, the role of evidence in building

claims, and the cultural norms that shape the meaning of the scientific explanations (Chin & Brown, 2000; Kapon & DiSessa, 2012; McNeill & Krajcik, 2008; Songer & Gotwals, 2012; Odden & Russ, 2018).

Sensemaking is also characterized by active cognitive and social processes (Sezen-Barrie et al., 2020; Odden & Russ, 2018). Researchers suggest that sensemaking is the construction of meaning based on explanation of a phenomenon by using prior knowledge and unique experiences to notice and attend to specific ideas, concepts, and thoughts (Robertson & Richards, 2017; Sezen-Barrie et al., 2020; Weick, 1995). Moreover, sensemaking is considered as a social and cultural practice that reflects how people come to understand based on their identities, cultures, backgrounds, and histories (Bang et. al, 2012; Gutierrez & Rogoff, 2003; Nasir, Rosebery, Warren, & Lee, 2006; Berland et al., 2016). Therefore, providing opportunities and learning spaces for students in which they can engage in rich, culturally responsive, and relevant interactions is critical to cultivate meaningful and equitable sensemaking moments for students in science (Bang et al., 2012; Gay, 2010; Ladson-Billings, 1992; Schwarz et. al., 2021; Windschitl & Calabrese Barton, 2016).

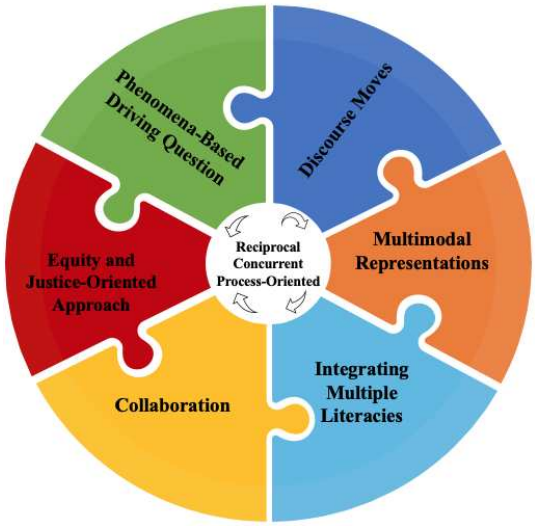
The literature on the NGSS uses the term sensemaking in a similar way (Schwarz, Passmore & Reiser, 2017). A number of scholars highlight the use of language-rich practices for sensemaking and the centrality of interaction to go about the sensemaking activity (Quinn, Lee & Valdés, 2012). Sensemaking relates to using language to engage with scientific practices with others, to transition from more naïve conceptions of the world to more canonically based, scientific ideas. Further work describes sensemaking as a simultaneous activity in terms of explaining a phenomenon (in a back-and-forth dialogue) as students actively engage and develop a deep level of understanding, rather than just a superficial understanding or memorization of facts (Berland & Reiser, 2009). Fitzgerald and Palincsar (2019) also agreed with Ford (2012) and Quinn, Lee, and Valdés (2012), that sensemaking is a social process, which happens around situated activity within the historical, social, and cultural contexts in which individuals interact with each other with the help of different tools.

Considering the existing socio-cultural and cognitive perspectives in explaining sensemaking, I acknowledge that different learning perspectives capture different components of the sensemaking process by highlighting individual and organizational levels of learning (Kelly, 2006; Lave & Wenger, 1991; Peressini et al., 2004; Wenger, 1998). I argue that sensemaking is

an ongoing process that happens not only from the individual level, but also from the systemic and collective levels as students begin to develop expertise by wondering and situating, predicting, explaining, critiquing, and co-constructing knowledge within the contextual circumstances and interactions they had in their community. With this mindset, the core questions become: How do we (as educators) provide such a learning environment for our students? What instructional practices do teachers need to embrace and implement in their science classrooms to foster their students' sensemaking process?

To address these questions, I propose six core sensemaking practices that potentially initiate and foster student sensemaking experiences by using (see Figure 2): a) relevant and meaningful driving questions to spark student interest and wonderment about phenomena, b) reciprocal discourse moves to cultivate student participation and involvement, c) multimodal representations to diversify different epistemic tools for students, d) developing and integrating mathematical and language literacy with science literacy, e) collaboration with meaningful interactions, and f) working towards equitable and justice-oriented learning environments in science classrooms.

Figure 2. Practices to Foster Students' Sensemaking Experiences in Elementary Science Classrooms



Before delving into the characteristics of each practice, it is important to unpack how and why I select each of these practices and choose to connect them with sensemaking. First, these six sensemaking practices involve opportunities for students to *identify, explain and critique science phenomena*. They help them to engage and experience phenomena; pose questions, predict, and interpret them by investigations; and explain the phenomena using situated

experiences and knowledge based on everyday community-based and critical knowledge over time (Horn et al., 2017; Russ et al., 2016). Second, these six practices are *reciprocal in nature* as both the teacher and students use and respond to them actively. These practices are not only used or activated by the teacher but are also utilized, contextualized and gain meaning as students use and respond to them. Further, implementation of these practices highlights the reciprocal relationships, not only between humans (such as teacher-student or student-student relationship and interaction), but also foregrounds the role and agency of more than the human world in sensemaking experience (Barad, 2007; De Freitas, 2016). Our interactions with non-human bodies (such as materials, objects, artifacts, nature, and environment) impact our experiences in noticing and sensing the world around us (Barad, 2007). That's why I refer to these practices as "sensemaking" practices instead of "teaching" practices, as they inform not only the process of teaching, but also the process of learning as students uses them to make sense of the phenomena. Besides, reciprocal use of sensemaking practices help students to see and position themselves as the *doers and knowers of science*, collective constructors of the knowledge and growing experts in the classroom since they can engage with and explain a variety of phenomena, concepts, and living and non-living elements of the environment. Finally, these are *process-oriented, inter-connected* and *transferrable to multiple local and global context*. The practices interchangeably work together instead of focusing on reaching a specific learning outcome or being destination oriented. Rather, these practices reinforce each other recursively and concurrently as the pieces of a puzzle and each has an equal amount of significance in the process of students' figuring out multiple science ideas and phenomena over a period.

Driving questions

In unpacking the characteristics of each practice, I'd like to start with the significance of using relevant, meaningful, and critical *Driving Questions (DQs)* of a science phenomenon to initiate and foster students' sensemaking experiences. In a way, DQs become the core initiator and navigator of the whole sensemaking experience. This is because, they help students to find the meaning and relevance of the science phenomena based of off their prior experiences. They spark curiosity and creativity and become a pathway for students to figure out how the world around them works (Krajcik & Shin, 2014). Teachers use driving questions (which could be unit and lesson specific) to engage students with the relatable, observable, and natural phenomena and use them to raise the question of how and why the selected phenomena happen and works

(Baek & Schwarz, 2015; Berland et al., 2016; Krajcik & Shin, 2014). As students experience the phenomena (ideally from a first-hand experience), they also start generating their own questions in relation to their own interest, observations and noticings based on their prior knowledge and experiences to make sense of the relevant phenomena. Therefore, both teacher's and students' use of meaningful, investigable, contextualized, and feasible driving questions is critical in elementary science classrooms as students constantly circles back to the DQ and engage and make meaning out of them (Krajcik & Czerniak, 2018; Krajcik, Miller & Chen, 2021).

Discourse moves

Discourse moves leverage students' participation by helping them to interact with the DQ as they ground their own questions, and collectively express and build their own ideas within a meaningful and productive discussion environment (MacDonald, Miller & Lord, 2017; Rosebery et al., 2015; Rosebery & Warren, 2008). These productive and meaningful discussions within the use of discourse moves also constitutes the forms of science talk (Ballenger, 2004; Gallas, 1995; Rosebery et al., 2015). In other words, discourse moves act as a reciprocal tool for teachers and students in facilitating discussions and promoting meaningful student talk and sensemaking (Bansal, 2018; Carpenter et al., 2020; Colley & Windschitl, 2016). More specifically, these moves help teachers to initiate student questioning and move student thinking forward. They are associated with fostering productive academic and disciplinary talk among students (Carpenter et al., 2020; Donovan & Bransford 2005). For instance, MacDonald and colleagues (2017) identified a variety of facilitative discourse moves that teachers and students can use to support sensemaking environment in science lessons. For example, helping students to clarify and elaborate their thinking and deepen their reasoning by using evidence to support their claims; making students' ideas public by revoicing them; emphasizing a particular scientific idea; supporting students to listen to other's ideas; and applying students' own thinking to others' ideas constitutes the core of teacher discourse moves. All these moves allow teachers to consider, appreciate and leverage students' ideas, rather than evaluating the correctness of the idea. For example, if the discourse move is "clarify a student's thinking," the teacher is tasked to use questioning and prompts to seek clarification on the student's idea. Thus, discourse moves direct the teacher's attention to the substance of the students' ideas and provide a chance for students to reflect and build on their peer's ideas. Such learning spaces support students' active learning as

a knowledge building activity and enrich their science learning experiences (Gotwals et. al., 2022; Wright & Gotwals, 2017).

Multimodal representations

Incorporating multimodal representations are essential for students to communicate with and figure out science ideas through different modalities like building models and using verbal or non-verbal modes of expressions (Salgado, 2021; Schwarz et al., 2009; Tang, Delgado & Moje, 2014; Zangori et al., 2017). Each type of multimodal representation (models, drawings, drama, gestures, visuals, diagrams etc.) plays a complementary role in supporting students while using science practices and explaining phenomena. Students' use of multimodal representations allows them to offer their ideas and questions in different formats. One of the critical ways to facilitate multimodality in science learning is developing and using models (Pierson et al., 2021; Schwarz et al., 2022). Models and modeling can include different modes of representation such as visuals, symbols, gestures, actions, physical materials, mathematical expressions, and written and oral language (Boulter & Buckley, 2000; Spikol et al., 2017). Considering modeling as a powerful and expressive sensemaking tool and practice, prioritizing the discussion of what counts as modeling and exploring for whom, how and why this practice might take different forms and shapes in communicating and making sense of knowledge. In other words, work of multimodality in science should be leveraged by providing more equitable or culturally responsive practice of modeling for student by including other modes of expression such as art, drama, ethno-dance, and narration of stories. Some existing work eloquently explores how we can define and explain modeling and its possibilities to expand the definition of it (e.g., Chappell & Varelas, 2020; Scherr et al., 2013; Solomon et al., 2022).

Multiple literacies

Centering and supporting students' *multiple literacies, such as their mathematical and language* skills is another critical practice to support students' sensemaking experiences in science**.** In a diverse and globalized world, the assets of community, culture, and language become even more important for students' growth and learning trajectories. Today, it is essential for teachers to support language and literacy development as one of the strengths of students' funds of knowledge (Gotwals & Wright, 2017; Moll et al., 2006). Teachers can make use of students' home language to promote science sensemaking in English (Gutiérrez & Orellena, 2006; Quinn, Lee & Valdés, 2012). They can also speak the shared home language with their students to

reinforce and communicate the key science phenomenon and vocabulary. Additionally, teachers can encourage students to communicate using combinations of their home language and English through "translanguaging" (García, 2009). Especially students identified as emergent bilingual children need support in the form of validation in using more linguistic resources as a tool to explain and explore phenomena, to ask questions, read, write, and discuss new information, and to use new words in multiple contexts as a part of their sensemaking experiences (Gotwals & Wright, 2017). In addition, based on the current reform documents in science and mathematics education, there is strong philosophical and empirical support for the integration of science and mathematics education to promote science and mathematics learning and improve student understanding toward these disciplines (Berlin & Lee, 2005; NGSS, 2013). Such integration may lead to enriched sensemaking and classroom experiences, cultivate student participation in science learning, and improve students' interest and achievement in both science and mathematics (Berlin & Lee, 2005).

Collaboration

Collaboration, an essential element to support students' sensemaking process, has three key features: a) the mutuality of exchanges, b) the achievement of joint attentional engagement, and c) the alignment of group members' goals for the problem-solving process (Barron, 2000). More specifically, having meaningful exchanges on the joint effort is essential for students in working to pursue solutions together. The multiple shared activities by fostering discourse environment can help students to achieve interpersonal goals together in the context of collaboration as they identify a problem and co-construct solutions together (Barron, 2000). Being a part of collaborative investigations puts students into an interactive social situation, and promotes problem-solving skills (Damşa & Ludvigsen, 2016). Sharing ideas, tools, and resources, as well as navigating various discourse moves enables students to center the social and intellectual interaction and help them to capitalize on the body of knowledge shared with the community at large (Stetsenko, 2005). Collaborating with their peers and teachers, students experience meaningful conversations that will help them adapt to our fast-changing, knowledge-based society (Darling-Hammond, 2008). It also allows students to express their ideas and raise questions with self-confidence and helps them bring out their voices and realities. Also critical to frame and move the sensemaking approach from an individual perspective to more humanizing, social and collective approach.

Working towards equitable and justice-oriented science learning environments

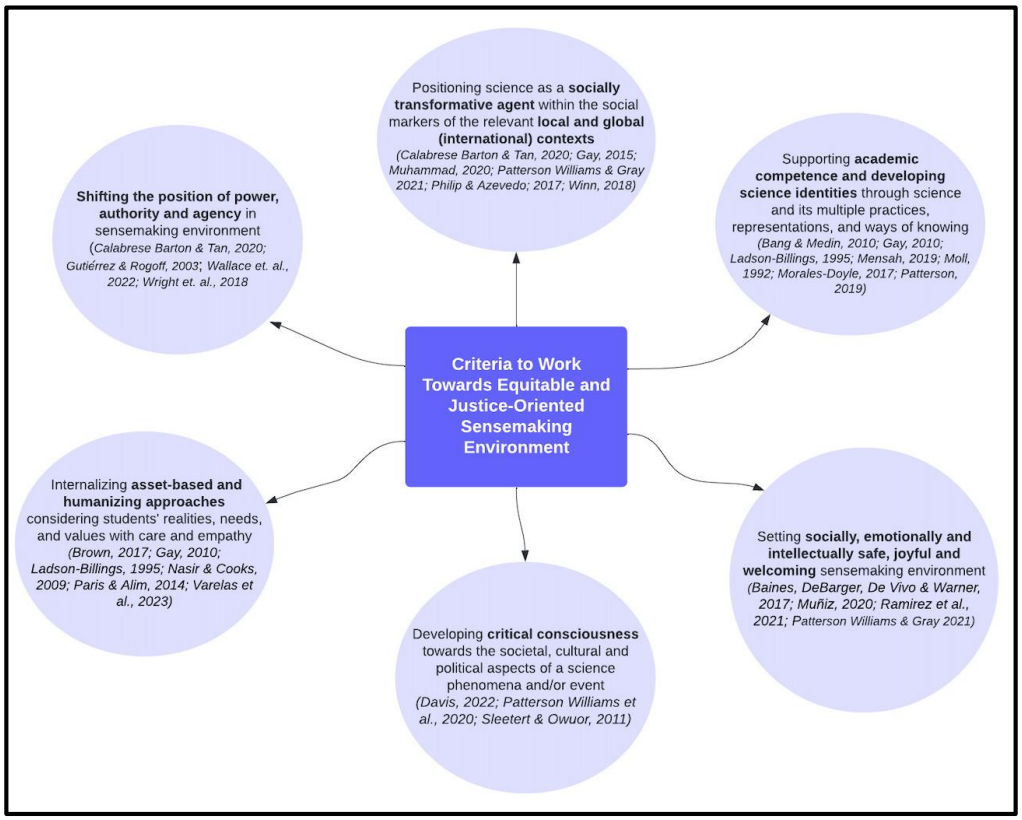
Working towards an *equitable and justice-oriented science learning environments* is one of the key and critical goals to support students to form meaningful and relevant sensemaking experiences and develop critical consciousness integrating social, historical, political, and cultural contexts of science and society (Bang & Medin, 2010; Calabrese Barton & Tan, 2020; Haverly et. al, 2022; Muhammad, 2022; Patterson Williams & Gray, 2021). Considering the field's growing commitment (e.g., Philip & Azevedo, 2017; Tzou et al., 2021), with this particular sensemaking practice, I also aim to address the ways in which how to develop equitable and justice-oriented sensemaking environments for students, how to support their developing science identities, and how to help them to become critical consumers, designers, and developers of science knowledge. Towards that end, variety of influential theoretical and empirical studies within the lenses of culturally relevant and responsive science teaching pedagogies supported me to conceptualize number of criteria in defining and implementing equitable and justice oriented sensemaking environments. Considering the complexity of criticality of this particular sensemaking practice, I suggest 6-sub criteria (guideline) on how to define equitable and justice oriented sensemaking environment and how teachers can facilitate such learning environment in their elementary science classrooms (see Figure 3).

Supporting students' *academic science learning and competence* by engaging them with science and scientific practices becomes critical for students to understand how science works, how to figure out and explain science phenomena, and how *scientific habits of mind and positive science identities* can be developed (Gay, 2015; Krajcik & Shin, 2014; Ladson-Billings, 1992; Morales-Doyle, 2017; Patterson Williams & Gray, 2021; Schwarz et al. 2017). More specifically, providing students opportunities to make sense of phenomena through hands-on and minds-on within inquiry and project-based science learning experiences that align with the standards become essential to leverage meaningful, quality, and equitable science learning experiences for them. As students becomes the member of such learning environment and feel belong to their science learning community, they can start developing positive science identities and leverage their academic competence.

Internalizing *asset-based and humanizing mindset* becomes another key criterion. Elementary teachers in their science lessons need to be mindful of positioning each of their students as builders, doers, and critics of science knowledge by highlighting their assets in the

learning moment in an authentic and age-friendly ways (Brown, 2017; Paris & Alim, 2014). Building positive and humanizing relationships by sharing personal experiences and stories to connect students to each other and to science can strengthen their sensemaking experiences. Moving away from deficit perspectives can give students a meaning and a motivation for science learning (Davis, 2022; Sleeter & Owuor, 2011).

Figure 3. Criteria (Guideline) to Define Equitable and Justice-Oriented Practices



I also argue that sensemaking experience can be leveraged and complemented by *social-emotional learning experiences* (Baines et al., 2017; Durlak et al., 2011). I conceptualize sensemaking as an ongoing and reciprocal learning opportunity to connect to others socially and emotionally for developing ownership and science identities, establishing critical consciousness in a safe learning environment, and maintaining positive and joyful relationships in their learning communities (Condliffe et al., 2017; Muñiz, 2020). Therefore, sensemaking and SEL experiences (such as self-reflection and self-awareness, building ownership etc.) are connected; work closely together; and reinforce each other in science classrooms as students and teachers engage with the various sensemaking practices (Ramirez et al., 2021).

Shifting the position of power and authority from teacher to students in classroom also makes a visible difference in terms of leveraging students' agency, ownership, and expertise in the learning environment (Gutiérrez & Rogoff, 2003; Patterson Williams & Gray, 2021). More specifically, giving students choices in the decisions of what questions to ask, how to connect science into their families and communities, and how to conduct and design investigations help them to position themselves as the experts since they can make connections to science phenomena, recognize, and build on the resources they bring from their own communities, and co-construct the knowledge with their peers (Bang & Medin, 2010; Wright & Gotwals, 2017)

Finally, positioning science as a *socially transformative agent* and guiding students to *developing critical consciousness* are imperative for students to identify, critique and eventually take proactive steps about the existing social injustices and deviated power structures in relation to issues on science, environment, and society (e.g., environmental, racial and gender-based injustices in science) (Calabrese Barton & Tan, 2020; Varelas et al., 2023). Elementary teachers who teach science need to be intentional with engaging their students in critical discourse around the historical, ethical, and societal impacts of science and what social markers (such as race, class, gender, language, SES, and other topics) play a critical role in such a discourse. It is also equally critical to consider *multiple local and global (international) contexts* when bringing the historicized and critical lens to examine the issues in science and society for transformation. It is imperative that science educators' decisions and actions are guided by the realities of local contextuality based on the different configurations and markers of students and societies in different nations (Gay, 2015; Milner, 2010; Villegas & Lucas, 2002). For example, an elementary teacher from Michigan can problematize the Flint water crisis (Hanna-Attisha, 2018) to unpack the issues of water quality and water access and its damaging affects especially for the people of color as an environmental justice issue. Meanwhile, an elementary teacher from Turkey can problematize the earthquake hit southeast Turkey (Patil, 2023) by considering the active geological processes, such as plate tectonics, and how natural hazards in Turkey heightened their impacts for certain ethnic communities with low SES and leads to a basic necessities like shelter, food, clean water, and sanitation.

CHAPTER 3: CONTEXT OF THE STUDY

This study takes place within multi-layered contexts of the local institutional (school and study), research (ML-PBL project), and curricular (ML-PBL curriculum) contexts.

Local And Institutional Context

This study takes place in a small-sized city located in the Midwest of the United States. Despite being impacted by an economic challenges and smaller population (which is overly White population), the city has local educational infrastructures that facilitate youth's experiences such as a community college, nearby university, and the community center. The Elementary School that I visited is a public school located a southern part of the city which is in a distant rural setting. The general student population of the Elementary School is around 300 and the school serves PK-3. While more than %50 of students scored at or above the proficient level for math, and more than 60% scored at or above that level for reading (cite the school website). Staff and educators are predominantly white, while the school's minority student enrollment (student population with Asian, African, and Latino immigrant families) is around 3%. The school enrolls more than 55% economically- disadvantaged students.

More specifically, Ms. Spark comes from a working-class family and was born and grew up in the same rural communities of Midwest that the school resides. She identifies herself as a white, middle-aged woman, a mother, and as a passionate farmer who loves agriculture. She specifically notes that she grew up engaging with agriculture and she is passionate about farming and teaching science. She claims that agriculture is one of the reasons that she feels belong in science and enjoy teaching science. She also simultaneously works as a farmer and runs a trucking business when she is not teaching during the year. Ms. Spark taught a variety of different core subjects for different grade levels in K-8 public elementary school in a rural district of Midwest more than 20 years. In the last 7 years, she started solely focusing on and teaching elementary science. In the first 3 years, she taught elementary science using traditional practices. After learning about the ML-PBL program, she participated in several professional learning sessions and started to use new practices in her 3rd grade science classroom for the last 4 years. Ms. Spark is also known as a highly empathetical and caring teacher in her school who constantly show effort and investment to get to know her students better. She prioritizes having constant conversations and building relationships with the parents and families of their students. In that way, she knows more about the family backgrounds, livelihood, values, and struggles of

her students and their families. She shares that many of her students has economic hardships, divorced parents or parents who are in jail. 85% of students in the school is eligible for free and reduced lunch. The total student sample in her 3rd grade classroom approximately divided across genders (60% female) with a racial composition of 90% White, 4% Black, 4% Hispanic and 2% multi-racial. Only about a seventh (10%) of students are identified as English-language learners (ELLs).

I purposefully worked with Ms. Spark to construct this longitudinal case. First, she was representative of her local community and teaching community in terms of her gender, racial and socio-economical background, I also argue that Ms. Spark's case can be illuminating for many teachers both in Midwest area and other areas (states) of the US. Considering the social markers that she possesses, as being a White, middle-class, cis-gender woman, number of pre-and in-service elementary teachers' backgrounds, needs, and teaching tendencies may overlap with Ms. Sparks' experiences. Therefore, I believe that this case will be valuable to unpack the challenges, transitions, and successes that a teacher goes through when recognizing, questioning, and drawing from multiple critical sensemaking and justice- oriented frameworks of science and teaching.

In addition, over the period of this study, it was notable to see that Ms. Spark was willing to take risks and investing time and energy into implementing the sensemaking practices and reflecting on her changing teacher identity. Even through there were times that she wasn't feeling confident in her practice, or she wasn't sure how to make transition from traditional practices to transformative and reform-based practices, her interest, effort, and dedication to support students' sensemaking experiences were quite powerful. Finally, Ms. Spark was collaborative, responsive, and willing to discuss her teaching experience before and after each of my visits to the class and throughout the analysis process. Therefore, I deeply enjoy collaborating and learning with Ms. Spark while crafting the snapshots and reflecting on changing patterns in her teacher identity and teaching trajectory.

Research Context

This longitudinal qualitative case study is grounded in a larger research project (Multiple Literacies in Project-Based Learning- *ML-PBL*). ML-PBL is project -based, theory-driven, and practice-grounded collaborative work responded to the need for a research-based, innovative intervention to deepen students' use of scientific knowledge and practices and increase their

academic, social, and emotional learning (Krajcik et al., 2023). Therefore, the research and curricular context of the study draws from *Project-Based Learning* approach to science as ML-PBL encompasses the core features of PBL. More specifically, PBL aims to leverage an inquiry based learning environment where students a) seek solutions relevant to learners' lives, b) use big ideas to frame 3-D learning goals, c) explore the question by participating in scientific practices to "figure out" why phenomena occurs and learn important ideas in the discipline, d) collaborate with others to find solutions, and f) create artifacts that address the driving question and represent knowledge (Krajcik & Shin, 2014).

Over five years, ML-PBL underwent several rounds of revisions and testing by partnering with multiple states and counties of the US, including classroom pilot studies, field tests, and efficacy study to determine whether the ML-PBL classrooms enhanced students' science academic, social, and emotional learning (Krajcik et al., 2023). This dissertation study attends to a subset of the ML-PBL project data through Ms. Spark's 3rd grade classrooms in the years of 2018-2019, 2021-2022 and 2022-2023. In this particular study, I grounded this work with Ms. Spark in politicized trust, which allowed us to be honest and vulnerable in navigating the challenges and dilemmas that may arise from institutional norms or power relations that intersect with our partnership work (Kaijser & Kronsell, 2014; Vakil et al., 2016).

Another key component of the project was providing professional learning (PL) sessions in each year to all ML-PBL participant teachers, including Ms. Spark. As she starts teaching ML-PBL curriculum in 2018-2019 school year, Ms. Spark attended to number of professional learning (PL) sessions in the beginning and during the years of 18-19 and 19-20. On average, ML-PBL teachers received approximately 7 days of PL (in-person and online hours) throughout the school year. Key aspects of PL included understanding the main features of PBL, reviewing the scope and goal of the units, enacting, and exploring some of the investigations that students would engage during the lessons, and learning about the construction of various student artifacts and assessments (Krajcik et al., 2023). The PL sessions supported Ms. Spark in implementing this new and innovative curricula to ensure providing equitable sensemaking opportunities for students that are culturally and historically responsive to the students, their families, and their communities. During the PL sessions, researchers and teachers all come together with a goal of making elementary science education more equitable and sensemaking oriented.

In these sessions, researchers and teachers work together to negotiate the ways in which creating classroom environments that affirm cultural identity, responsible ownership, and collaborative productive relationships. PL also assists the teachers to build supportive, positive, and critical teaching and learning community with their fellow teacher colleagues and researchers of the project. In crafting meaningful discourse during the sessions and listening each other's experiences on implementing and navigating ML-PBL curriculum, teachers were able to solicit ideas from each other and validate their contributions and growth as teachers.

Curricular Context

In supporting students' sensemaking experiences through sensemaking practices, it is critical to provide quality curricular context and materials for students to engage in practices to figure out what causes phenomena to occur. To do so, project-based learning (PBL) becomes one of the meaningful approaches to guide students in investigating and constructing explanations and introducing and reinforcing the phenomenon for productive discussion (Fitzgerald & Palincsar, 2019; Herrenkohl & Cornelius, 2013; Mercer & Home, 2012; Muñiz, 2020), as students develop their sensemaking experiences. More specifically, PBL-aligned classrooms and curriculum materials potentially support students' science competency, engagement, and social-emotional learning (SEL) in sensemaking (CASEL, 2013; Durlak, 2015; Taylor & Booth, 2015).

Adopting the principles of project-based learning, Multiple Literacies in Project-Based Leaning (ML-PBL) is a curricular system (2^{nd} to 5^{th} grades), emphasizes on student's experiences in figuring out phenomena and investigating questions that they find relevant and meaningful while working together to construct knowledge and solve problems (Krajcik & Shin, 2014; Miller & Krajcik, 2019; Krajcik, Palincsar & Miller, 2015). The alignment between the ML-PBL curriculum and sensemaking practices encouraged me to investigate how the implementation of sensemaking practices would look and inform elementary students' sensemaking experiences in science. More specifically, ML-PBL advances science teaching and learning experiences for teachers and students by instantiating the main components of situated learning, active construction, cognitive tools, and social and cultural interactions (Miller & Krajcik, 2019). Third grade ML- PBL units include Squirrel, Toy, Bird, and Plant Units (chronologically), are designed to engage students, and sustain their efforts in making sense of the phenomena.

Table 1. Potential Ways to Incorporate Sensemaking Practices within the Curricular Content of the 3rd Grade ML-PBL Units

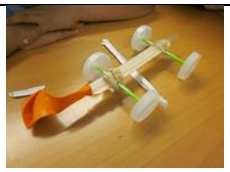
Sensemaking Practice	 **UNIT 1: Squirrels** *(6 Learning Sets with 29 Lessons)*	 **UNIT 2: Toys** *(4 Learning Sets with 19 Lessons)*	 **UNIT 3: Birds** *(6 Learning Sets with 32 Lessons)*
Phenomena-based Driving Question	***Unit DQ:*** Why do I see so many squirrels, but I can't find any stegosauruses? ***Phenomena****:* Animals meet their needs to survive in their environment in different ways.	***Unit DQ****:* How can we design fun moving toys that kids can build? ***Phenomena****:* Forces are needed to make a moving object start, stop, slow down, or change directions.	***Unit DQ:*** How can we help the birds near our school grow up and thrive? ***Phenomena****:* Birds migrate in flocks. Different species have features that influence their eating, foraging, and social behaviors.
Discourse Moves	***Discourse Move:*** Help students apply their thinking to others' ideas *(LS1.4)* ***Suggested prompt for teachers:*** *"What was the squirrel doing? Can you show us by acting it out? Why do you think the squirrel might have been running up the tree? How did running up the tree help it to meet that need?*	***Discourse Move:*** Help students listen carefully and think about one another's ideas *(LS2.5)* ***Suggested prompt for teachers:*** *"Why is it important to know about friction when we design toys? How does your idea relate to what was said by x? Can you explain how your idea is similar to or different?"*	***Discourse Move:*** Emphasize a particular idea (LS3.1) ***Suggested prompt for teachers:*** *"Can you say more about why warmth is important for the bird? How does the lack of water in the summer connect to your bird's needs?"*
Multimodal Representations	Students ***read a story*** called *Stone Girl Bone Girl* about one of the most successful female paleontologists, Mary Anning, and her discovery of Jurassic Era fossils. They use the story and video of Mary Anning to brainstorm how they could find more information about questions they find very interesting regarding squirrels or Jurassic Era fossils. *(LS5.6)*	Students collaboratively ***develop models*** in their groups. Students share ideas about ways to represent the patterns of motion and balanced and unbalanced forces. Using their initial toy models, they make predictions about the motion of their toy if they increase or decrease the friction in that area. They test their predictions and use this data to change the design of their toy models. *(LS2.4)*	Students ***analyze the online resources*** on the Audubon or Cornell Lab of Ornithology for information about their case study birds. They view text, media, and graphics (e.g., bird area map), and analyze bird sighting data. They consider bird behavior as related to a system, which includes birds' needs, changing seasons, and the environment. *(LS3.3)*

Table 1 (cont'd)

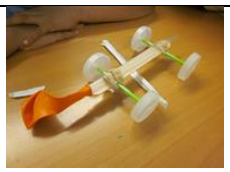
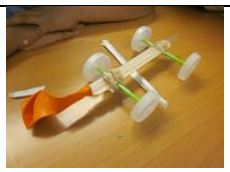
Sensemaking Practice	 **UNIT 1: Squirrels** *(6 Learning Sets with 29 Lessons)*	 **UNIT 2: Toys** *(4 Learning Sets with 19 Lessons)*	 **UNIT 3: Birds** *(6 Learning Sets with 32 Lessons)*
Collaboration	***Collaborative Group Investigation***: Fossil Sorting *(LS4.3)* In their small groups, students analyze the photographs of fossils from different time periods. As they choose one of the fossils from the kit, they start sorting, investigating, recording their observations, claims, and evidence in identification sheet together. As a group, they share about the fossils they have identified, the features of the fossil.	***Collaborative Group Investigation***: Magnetic and Electrical Forces *(LS3.5)* Students review the steps in their design process as they collaboratively discuss how their toys or parts of their toys could be moved by magnetic or electrical forces. In their groups, they develop ways to use magnetic and/or electrical forces in their toy designs, taking into account constraints related to materials and time available.	***Collaborative Outdoor Investigation***: Placing and Observing Bird Feeders *(LS4.5)* Students discuss in their small groups what decisions they have made and build their bird feeders. Students put the food in their bird feeder and place it where they think it should go outside. Once back in the classroom, the groups evaluate how well their feeder worked and what changes they can make if necessary.
Integrating Multiple Literacies to Science (Math Literacy and Language Support)	***Math Learning Goal:*** Students can generate data by measuring lengths to the half and fourth of an inch; and they can represent measurement data in halves and fourths of an inch on a line plot. *(LS2.3)* Students predict how far a squirrel can jump, then they participate in a jumping contest. They graph the different jumps and compare their jumps with those of a squirrel.	***Math Learning Goal:*** Students use mathematics to record and compare the different distances that cars travel across different distances. *(LS2.3)* Students determine the impact of different surfaces and friction. They launch cars and observe and record the distance the cars travel on poster board (or floor tile) and a towel (or carpet). They generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch.	***Math Learning Goal:*** Students analyze data to identify similarities and differences in snowy owl sightings and migration patterns over 2 years. *(LS3.6)* Students watch a film about the snowy owl which highlights how scientists have been studying changes in snowy owl. Students analyze snowy owl sighting data in their own state from 2 years—2016 and 2017, answer math questions, and identify patterns.

Table 1 (cont'd)

Sensemaking Practice	 **UNIT 1: Squirrels** *(6 Learning Sets with 29 Lessons)*	 **UNIT 2: Toys** *(4 Learning Sets with 19 Lessons)*	 **UNIT 3: Birds** *(6 Learning Sets with 32 Lessons)*
Working Towards Equity and Justice-Oriented Approach (through equity and SEL learning goals)	***Equity Learning Goal:*** **Constructing Critical Knowledge** ***(LS3.3)*** Students can explain phenomena using the lens of environmental and social justice by choosing a neighborhood in their city that doesn't have enough trees or has fewer trees than other areas. They use evidence to examine the relationship squirrels have with trees; and analyze photos of communities to predict whether there would be more squirrels (and biodiversity) in some areas than others. Students use the idea of a system as it relates to city design and experiences in different neighborhoods within equity perspective.	***Equity Learning Goal:*** **Sustaining Culture** ***(LS1.7)*** Students read the Lonnie Johnson story *Woosh!* to obtain information about the engineering design process and make connections and define solutions to their own toy design problems. Lonnie Johnson is an African American inventor and aerospace engineer who worked at NASA and invented the Super Soaker water toy gun. As they read about Johnson's story, students also use science, engineering, and technology to collect and strengthen by highlighting the voices and experiences of people of color.	***Equity Learning Goal:*** **Funds of Knowledge** ***(LS1.6)*** Students conduct interviews about birds with their family members. Guest speakers and/or students share their experiences and stories about their favorite birds. After each speaker, students are given some time to share questions with partners and discuss the different experiences in their classroom. Family interviews help students to recognize that each person in the class has a different cultural and linguistic history, experiences, and knowledge for learning and doing science.

In this study, I particularly pay attention to Ms. Spark and students' implementation of the first three units, since they are fully enacted before the school year ends. In each unit, students engage with a number of unit and lesson-level driving questions around a relevant phenomenon, asking their own questions, investigate real-world problems, and build artifacts (Krajcik & Shin, 2014). Table 1 above illustrates how and to what extent 3rd grade units incorporates and aligns with six different sensemaking practices, as well as how it aims to support students' SEL experiences. ML-PBL also positions equity goals as a pivotal component in its curriculum units. Equity goals require students to show their understanding and explain phenomena by being critical about how science is used and defined in different communities and

contexts using the lens of social justice and social, historical, and institutional factors. Therefore, ML-PBL curriculum sets five main equity learning goals in 3rd grade lessons across each unit. These goals aim to leverage students' sensemaking experiences by centering: 1) funds of knowledge, 2) place-based knowledge, 3) critical knowledge and awareness, 4) sustaining culture, and 5) structures of inequity and issues of social justice.

For example, in the beginning of each Unit, students conduct *family interviews* with the members of their families to connect their personal experiences and funds of knowledge (Moll et al., 1992) which passes through generations to science. In one of these interviews, students and their family members engage with the question of: "Some families and cultures have a special relationship to a certain kind of bird. Does your family or culture have a story that you can share?" to evaluate and communicate information from family stories about different types of birds. Encouraging students to conduct family interviews support them to bring their family and community voices and values in science classrooms. Family interviews, a staple in social studies, also offer a compelling and meaningful way for students in science classrooms to include their cultural backgrounds, ask questions about experiences with science, listen to others carefully, and respond to what others say in a meaningful manner. It also assists teachers to know or think more about students and their families and help them to rethink what to do when negotiating appropriate responses to students' needs (Akgun, Miller & Codere; 2021). Therefore, ML-PBL's equity and SEL goals mostly aligned with the offered equity and justice-oriented sensemaking practices in this study (see Figure 3). Nevertheless, there is always space for pushing further and bringing more critical, humanizing, and justice-oriented science content and perspective to the curriculum materials where it can be applicable in multiple local and global (international) contexts (Berland et. al., 2016; Bielaczyc, 2013; McNeill & Krajcik, 2008). Therefore, it's critical to keep design and redesign quality curriculum materials to both support pre and in service teachers to do this challenging and critical justice-oriented work.

Finally, through the SEL goals, ML-PBL aims to center students' linguistic, cultural, and intellectual resources by providing them space to self-reflect, identify problems that are important to them, take an ownership in co-constructing the knowledge to solve these problems, and build sensemaking experiences collaboratively by interacting and working with the other members of the learning community. Contextualizing the sensemaking experiences within the ML-PBL units, I argue that ML-PBL can provide students an opportunity to make sense of a

phenomena and exercise ownership, by concurrently and constantly engaging with various sensemaking practices and learning goals. Therefore, the 3rd grade ML-PBL classrooms allow me to contextualize and investigate my argument on how the proposed six sensemaking practices can be leveraged and implemented in elementary science classrooms, and to what extent implementing these practices might both promote students' sensemaking experiences and teacher's growing and reform-based teacher identity.

CHAPTER 4: METHODOLOGY AND METHODS

Research Design

The goal of the study is to investigate the ways to capture and interpret the science teacher identity development considering teacher's individual, collective and practice-level life experiences. Therefore, this study specifically aims to explore the relationship and interaction between the three levels (individual, collective and practice) of identity resources in shaping the ways of developing teacher identity. The study also aims to brings insights on the relationship between changing teacher identity and students' sensemaking experiences in science. To meet these goals, the offered theoretical identity and sensemaking frameworks will act as an analytical tool to investigate changing patterns of the teacher's practices, as well as developing identity over three years. I specifically investigate how an elementary science teacher's a) personal history and positioning (individual-level); b) conceptions towards teaching and learning science (collective-level), and c) changing patterns in implementation of *sensemaking practices* (practice-level) interact with each other to shape the developing teacher identity, as well as to students' sensemaking experiences.

To conduct this investigation, I craft a single case study using longitudinal qualitative research (LQR) since it considers time as fluid, subjective, and unbounded (Creswell & Creswell, 2018; Dyson & Genishi, 2005; Miles, Huberman, & Saldana, 2014). Longitudinal studies are critical to investigate and test working theories across multiple time periods and sources of data. LQR design helps researchers to take their time to thoroughly vet their claims and to refine their theory (Larbi-Cherif at al., 2021). Therefore, LQR approach helps me to investigate the affordances of multifaceted framework on how to capture the changing patterns in elementary teacher's individual, collective and practice-linked experiences as a person and as a science teacher (Balmer & Richards, 2022). It also guides me to generate critical knowledge and insights on how the systemic change in teacher's conceptions and instructional practices (and therefore teacher identity) relates to students' learning experiences in science. This longitudinal case also had its affordances to help me to represent how a project -based, and sensemaking and equity-oriented science teaching and learning environment look like. Over the years, my observational visits to Ms. Spark's classrooms and series of informal and formal conversations I had with her became instrumental to ground a collaborative, humanizing, and trustworthy relationship between us.

Considering the complexity of the inquiry process for conducting longitudinal case study, I specifically focus on Ms. Spark's 3rd grade science classrooms during the years of 2018-2019, 2021-2022, and 2022-2023. In each year, I primarily investigate the changing patterns in Ms. Spark's (and her students') implementation of sensemaking practices through observational field notes and video recordings. These resources allow me to make clear and evidence-based implications on what role the sensemaking practices play in the development of Ms. Spark's identity development and her students' sensemaking experiences. In other words, capturing the observable change in the implementation of sensemaking practices allow me to reflect on a) how Ms. Spark's identity was developed, b) how her conceptions and implementations are connected and transferred into each other, and c) how the changes in her practices and conceptions help Ms. Spark to lean more towards equity and sensemaking-oriented science teaching. In addition, I also draw from number of semi-structured interviews with that I conducted with Ms. Spark to reflect on her individual and collective experiences.

Researcher Positionality

My own positionality as a person, researcher, and teacher educator critically informs how and why I made the theoretical, instructional, and methodological choices I made to craft this study. Therefore, my positionality becomes a complimentary data generation point here in articulating the nature of the relationships that I built with Ms. Spark and students. My positionality informs the rationale of why I investigate these research questions, how I chose to generate and analyze data, and how I use certain methodologies that I employed (Neal & Gordon, 2001).

On a personal level, I identify as a Turkish woman who grew up in a Muslim society and working towards her Ph.D. in the US. This Ph.D. journey provided the possibility for me to work towards becoming a critical learner, researcher, and educator. Before starting to my journey in the US, I had worked as informal elementary science educator in Turkey for two years in science centers and museums. I also worked as a researcher in a project to study how to integrate and teach various aspects of nature of science in elementary science classrooms. I tried hard to support my students to have meaningful learning experiences in science and help them to understand what counts as science and what constitutes the methods and systems of doing and making sense of science. One of my priorities was working with students to find relevance and make connections with science in their lives. However, as I become a doctoral student and

engaged in critical conversations on the possibilities of science learning and teaching, I have realized that back then I did not take the full critical stance on and practices for equity, justice and sensemaking which today is the core of my science teaching and research agenda.

On a researcher and teacher educator level, these missed opportunities in the past help me to realize how I first need to invest into my own teacher identity work as a person who study and work abroad, and as a science educator who strives to move towards justice and sensemaking oriented education research. More specifically, my research and teaching experience in the U.S. led me to rethink about the changes that I've been going through in my personal and scholarly life in this new global community. Teaching to PSTs on how to teach elementary science and being a member of the ML-PBL project for years also impacted my positionality for this study. In the past couple years, I closely worked with the curriculum materials for 3rd grade science units and interacted with several 3rd grade teachers by visiting their classrooms and hearing their experiences on teaching ML-PBL units. My work with pre-service teachers (PSTs), and with ML-PBL teachers undoubtedly helped me to contextualize and situate the sensemaking practices into reality. It also encouraged me to take a critical lens on how to provide more critical, equitable and justice-oriented stance to sensemaking. The affordances and the challenges of the ML-PBL curriculum helped me to navigate and modify my sensemaking practices and give me an opportunity to provide future implications for teacher educators and curriculum developers. My relationships with PSTs and specifically with Ms. Spark also guide me to recognize and prioritize building meaningful, empathetical, and intellectual relationships with both pre and in service teachers. During the years that I visit Ms. Spark's classrooms, I seek to build and maintain a strong, humanizing, and professional relationship with her and her students. As I watch her interact with students, I realize how she pays attention to their needs and questions, and guide each of them to investigate and make meaning out of the phenomena. I deeply valued her stance and respected the input and expertise that she brings into this study. I learn with and from her on how to teach science by prioritizing their family backgrounds and interest, as well as their social, emotional, and academic needs in learning science.

I believe all these personal and collective experiences I had informed my developing researcher and teacher educator positionality and made me question: how does shifting social, cultural, and institutional contexts of learning and teaching interacts with one's approach to teach and learn science? what is the relationship between the developing teacher identity and

practices we implement to teach? These lingering questions influenced my stance towards this particular study because I prioritize to learn more about how to support students in making sense of science phenomena considering their communities' social and cultural contexts. Therefore, my focus becomes investigating how to support students' equitable sensemaking experiences in science, and how teachers' transition into reform-minded science teaching practices can support students' critical sensemaking experiences. This question motivated me to offer six-sensemaking practices within equity and justice lens which can be feasible to implement in multiple contexts.

Instruments and Data Generation

Teacher-level data generation

For generating teacher-level data, I focus on two main data sources. Observation field notes (within the video-recordings) and semi-structured individual interviews with Ms. Spark constitutes the teacher-level data. To generate the observational field notes during my classroom visits, I use observation protocol to critically reflect on the extent of Ms. Spark and students' implementation of sensemaking practices. Second, using several semi-structured interview protocols in each school year, I bring deeper insights on Ms. Spark's personal background, conceptions of science, and her interpretation and re-interpretation on implementing various sensemaking practices.

Video recordings and observational field notes

During the years of 18-19, 21-22 and 22-23, I visited, observed, and took detailed field notes for 28 lessons of Ms. Spark's science classroom (see Table 2). Video recordings of each observed class also helped me to re-analyze and re-interpret certain teaching moments and supported me to enrich my field notes. All these video recordings left me approximately 20 hours of video data to analyze.

Table 2: Teacher and Student-Level Data Generated for Each Year of the Study

School Year	# of video recordings (Observational field notes)	# of audio recordings (Interview transcripts)	# of student work (DQB, artifacts and assessments)
2018-2019 (Y1)	4	2	1+1+1
2021-2022 (Y2)	12	3	3+3+3
2022-2023 (Y3)	12	2	3+3+3

For the first year (2018-2019), there were 4 classroom videos and therefore 4 observational field notes from Ms. Spark's classrooms as the main data source. The first-year data is generated by one of the research associates of the ML-PBL project. For the years of 2 and 3, I have purposefully selected 4 focal lessons from each unit, and personally visited these classes. To select the focal lessons, I first went through the ML-PBL curriculum to identify learning performances and goals, figuring out statements, and evidence statements of each lesson of the learning sets. For Y2, I purposefully select focal lessons where students engage with various science and engineering practices, conduct small and whole group investigations to build models and end of unit artifacts, and where they integrate science and math learning experiences together. For Y3, I prioritize to select focal lessons with equity and SEL learning goals (see Table 1) where students reflect on science phenomena through critical lens. In that way, I create a rich selection of classroom visits with the spectrum of using different sensemaking practices within the ML-PBL curricular content between the years of 2018-2023.

In generating the observational field notes, I used observation protocol (see Table 3) to identify the extent and change of Ms. Spark and students' implementation of sensemaking practices over three years. The protocol is created and refined by the members of the ML-PBL team. The protocol was not created as a checklist; instead, it highlighted the principles of PBL. Through the evidence statements of the protocol, observers received specific directions to look for ML-PBL strategies which are used not only by the teacher but also the students. The protocol guided the observers to take field notes and score how well the teacher and the students were involved in using the DQ to figure out phenomena, using discourse moves, and using multimodal representations in collaboratively building artifacts and conducting investigations. Even though the original observation protocol does not fully address the content and expectations of all six sensemaking practices, it guided me to take the detailed field notes and bring evidence to the level of Ms. Spark and her students' use variety of sensemaking practices. In addition, observation protocol includes a four-point Likert scale ranging from 1 = minimal or no support to 4 = provides meaningful support for students in sensemaking. Table 3 below shows an example item from the observation protocol which represents the extent of the teacher's use of multimodal representations as one of the sensemaking practices.

Table 3: Example Item from Teacher Observation Protocol (Highlights the Practice of Multimodal Representations)

Teacher instructional practices	Evidence statement	Score
Teacher's support of reading, viewing, writing, and drawing/representing to figure out phenomenon and engage in sensemaking (Supports students to read and interpret multimodal representations [print text, audio, video, gestures, graphics/models] and make connections to other unit experiences and texts. Supports students to communicate their ideas clearly using writing and/or drawing/models (as appropriate to the LP). (q8)	Provides appropriate support for students to read and interpret multimodal representations, makes connections to other unit experiences and texts, AND supports students to clearly communicate their ideas that connect the texts to the LP or DQ.	4
	Provides some appropriate support for students to read and interpret multimodal representations, makes connections to other unit experiences and texts, AND supports students to clearly communicate their ideas that connect the texts to the DQ.	3
	Provides few appropriate supports for students to read and interpret multimodal representations, or makes connections to other unit experiences and texts, AND few supports for students to communicate their ideas clearly most of the time.	2
	Provides minimal or no appropriate support for students to read and interpret multimodal representations, make connections to other unit experiences and texts, AND does not support students to communicate their ideas.	1

Originally, the corresponding observation scores from the observation protocol led us to portray the patterns in the use of teaching practices. However, since I did not conduct quantitative analysis in this study, I did not assign numeric scores to identify Ms. Spark's and students' use of sensemaking practices, Instead, these numeric scores helped me to determine qualitative levels of to what extent they were able to implement the sensemaking practices (such as 4= stronger use; 1= weaker use). In that way, I identify the changing levels in their use of sensemaking practices over years by providing relevant evidence based on the expected evidence statement for each practice.

Individual semi-structured teacher interviews

I chose to conduct semi- structured interviews because I have several focal components to lead my analysis (the components of the teacher identity and sensemaking practices) that I would like to discuss with Ms. Spark. I see interviews as critical, open, and meaningful conversations in which the participants co-construct meaning, and a semi-structured interview provides the flexibility for such conversations (Hoskins & White, 2013). During 2018-2019, one

of the research associates of the ML-PBL project conducted two semi-structured interviews with Ms. Spark in the beginning and the end of the year. Following, I personally conducted three semi-structured interviews with Ms. Spark during 21-22. In the final year, I conducted two semi-structured interviews with her. During these interviews I had in-depth conversations with Ms. Spark in relation to her personal background, conceptions of science learnings and teaching, and experience on implementing sensemaking practices. As I aim to reflect more on her developing teaching trajectory within sensemaking practices, interview protocol also included questions focusing on her emotions, challenges, concerns, and successes in implementing each of these practices in her 3d grade science classroom.

These interview sessions (each around 45-50 mins) included questions (a) discussing her experience on transitioning from traditional to equitable and sensemaking-oriented instruction by using sensemaking practices, (b) identifying and interpreting how implementing these six practices was challenging over the years and/or successful in supporting students making sense of a phenomenon (e.g., in terms of using DQ, modeling, supporting collaboration and equitable and justice-oriented instruction etc.). In addition, to learn more about her personal background and changing conceptions on science learning and teaching, I ask questions in relation to her experiences as a person, learner and teacher during her early and following years; the social markers that identify her; her actions and interactions with youth, their families and other educators; her impressions on the community and institutional contexts (i.e., relationships with the school administration, principal, curriculum coordinator, and PL sessions with ML-PBL researchers); her values and priorities in defining ideal science learning and teaching space; and power dynamics around her. Besides these formal semi-structured interviews, I had number of informal conversations with her right before and after each class that she teaches. In that way, I was able to have more informal and honest conversations on her experience in teaching these selected focal lessons. In doing so, I aimed to delve more into her perspective and reasoning in implementing and modifying certain strategies and practices so that she could re-assess and re-interpret her interactions with the students and pedagogical decisions she made.

Student-level data generation

I collect three types of student work (DQB, artifacts and assessments) over three years period (see Table 2). The data consist of various written and verbal work of the students completed in class, including their inputs from driving question board (DQB), models and

artifacts they build, and formative and summative in-unit and end of unit assessments. First, *the DQB* becomes an essential student work to represent students' wonderments and engagement with the phenomena and the DQ. Ms. Spark guide students to use the DQB, so they can add their own questions and ideas in relation to the unit and lesson level DQ. The DQB allows students to represent and develop their thinking throughout the unit, as they go back to the DQB and add new questions and revisit the resolved ones at the end of each lesson.

Second, I collect *artifacts and models* that are part of the ML-PBL materials. At the end of the Squirrel Unit, students create a story, sketch, play, or model of how the stegosaurus did not survive and the eutherians did survive. At the end of the Toy Unit, students build moving toys and design portfolios related to those toys to show forces acting on the toy and directions for building the toy. Finally, at the end of the Bird Unit, students design bird feeders that consider the physical and behavioral traits of the bird they are concerned with, the changing weather and environment, and the needs for reproduction of the focal bird.

Third, *formative and summative assessments* are collected during each unit. These assessments included the formative embedded assessments, such as CER (Claim-Evidence-Reasoning) charts, and model constructions. The assessments were designed with items that used the three dimensions of learning to make sense of phenomena similar but not identical to the phenomenon or problem featured in the unit (Bartz & Chen, 2021; Li, 2021). ML-PBL team developed rubrics and scoring protocols for these items by reaching to the interrater reliability over the course of each unit.

Data Analysis

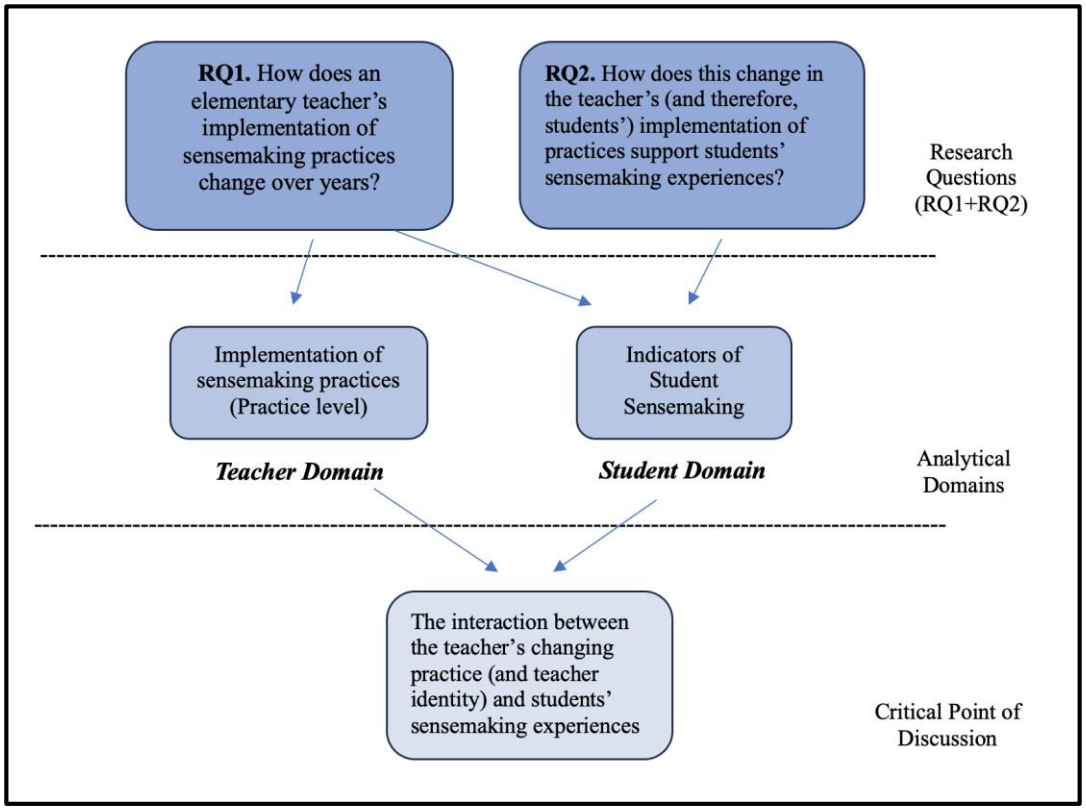
This study will investigate three main research questions (RQs) to delve into the developing This study will investigate three main research questions (RQs) to delve into the developing teacher identity and students' experiences in making sense of phenomena. In analyzing these RQs, I followed detailed steps of reflexive thematic analysis (Auerbach & Silverstein, 2003; Boyatzis, 1998; Richards, 2022). I engaged in the phases of identifying, analyzing, and interpreting patterns of meaning within the qualitative data sources I have. For each step, I offer examples of how to analyze the data (through the detailed analysis tables I create) and generated evidence trails to illustrate how I spotted changing patterns in the implementation of Ms. Spark and students' sensemaking practices, as I work to reduce data yet maintain meaning. I also engaged with a series of queries to address my reflexivity as a

researcher while initiating and proceeding through data analysis and interpretation (Saldaña, 2016; Smith & Osborn, 2008). In that way, I emphasize the reflexive nature of the decision-making that guides my thematic analysis process. Following, I address how I answer each research question by providing a detailed analytical procedure.

Analysis of RQ1 and RQ2

The first two research questions of the study are closely connected to each other, because while the first question investigates how Ms. Spark (and therefore, students) starts to engage in and implements sensemaking practices in 2018 and goes through changes in her implementation over the years until 2023 (see Figure 4).

Figure 4. Analysis Structure: Moving from RQ1 and RQ2 to analytical domains and critical point of discussion



By looking at the changing patterns in her implementation through RQ1, I addressed RQ2 of the study, because as Ms. Spark implements the practices, students also simultaneously enact them in a reciprocal and active way as they collaborate with their teacher and peers. Therefore, the analysis of RQ1 within the teacher data informed my analysis of RQ2 within the student data (see Figure 4). In answering RQ2, students' implementation of the practices and their verbal and

non-verbal work (artifacts, models, verbal discussions etc.) allowed me to infer their level of sensemaking experiences. To do so, I proposed a guideline that includes the indicators of student sensemaking. These indicators guided me to interpret how students' sensemaking experiences look each year as the teacher and students implement the sensemaking practices. Following, I will unpack the detailed steps of the analysis process for the RQ1 and RQ2.

Step 1 of the analysis: Annotating field notes and transcripts, and getting familiar with the data

The analysis for these overarching questions started with answering RQ1 since the teacher's changing implementation of sensemaking practices is one of the core analysis points of this study. Looking at Ms. Spark's implementation between 2018 and 2023 allowed me to a) make inferences on students' sensemaking experiences in RQ2 and b) make arguments on how Ms. Spark's practice level experiences act as a core component to capture her overall identify development trajectory in RQ3 (considering the implementation of practices is one of the core components of my identity framework).

Therefore, as an initial step to my analysis, I focused on my observation field notes and video recordings of each lesson that I visited during the period of 2018 and 2023. During each classroom visit, I took detailed field notes that describe and represent the critical events and moments where Ms. Spark and students enact sensemaking practices. To do so, I used the observation protocol (see Table 3) and drew from my definition of each practice, as well as the evidence statements from the observation protocol while I was taking my field notes.

Shortly after each classroom visit, I watched the video recordings of the focal lessons, and went through my field notes and interview transcripts again to refresh my mind on what critical moments occurred in the lessons. I paid particular attention to the moments that I had marked in my field notes as being of interest based on what had happened. Since I was initially looking at the opportunities and missed opportunities in using sensemaking practices by Ms. Spark and students, my attention was focused on evidence of using these practices, as outlined in the operationalization list and observation protocol (see Table 3). For instance, in a class observation or interview transcript, I might have seen a moment of discourse where certain discourse moves and prompts were used or not used. When I reviewed the video in this first round, I would return to that section in my field notes and add more information there about what happened. I also specified exchanges (quotations) between the teacher and students or among students where these critical moments took place, so I could use them as evidence to support my

claims in the analysis. Therefore, the first step of the analysis was to re-watch the videos and go through the interview transcriptions and field notes to create annotations and evidence to use in the future steps. This review enabled me to document my initial arguments based on the raw data that I had observed, heard, and was told by Ms. Spark and students.

Step 2 of analysis: Identifying critical moments

This second step of the analysis helped me to identify critical moments from each focal lesson that I observed in each year. After finalizing my work on annotating the raw data, I identified specific critical moments that illustrated Ms. Spark and students' experiences in implementing each sensemaking practice (SMP). Thomson and colleagues (2002) defined a critical moment as "an event or experience that the researcher or the [participant] sees as having important consequences on the [participant]". Aligning with this definition, I identify critical moments or events as where the teacher and students engage in events, investigations, discourse, or experience that signified Ms. Spark and students' use of practices and students' experiences in sensemaking. In that direction, I created three separate analysis tables to represent the evidence trails (critical moments) of each year. These tables allowed me to show how each sensemaking practice is used by the teacher and students in the focal lessons of the year. Table 4 shows an example structure of the analysis table that I used for each year (table illustrates Y2). Based on the raw data from each focal lesson, I assigned moments where specific SMPs are implemented by students and teachers. In that way, I was able to illustrate to what extent and how practices were enacted each year in an organized manner.

Table 4. Example Evidence Trail of Critical Moments in the Implementation of Sensemaking Practices

Evidence Trail **(Y2: 21-22)**	Implementation of Sensemaking Practices (SMP)					
	SMP 1	SMP 2	SMP 3	SMP4	SMP 5	SMP 6
Squirrel Unit						
Toy Unit						
Bird Unit						

I generated the content of the analysis tables using the raw data (observation field notes and student work) as the evidence which I've gathered through the step 1 of the analysis. To identify the critical moments that they used certain SMPs, I drew from my definition of each practice, as well as the evidence statements from the observation protocol (see Table 3). In that way, I was able to a) assign certain moments and events under certain practices in my analysis

table, and b) interpret the extent of Ms. Spark and students' level of using particular sensemaking practice. These identified critical moments constitute moments, such as where the teacher and students conduct small and whole group work, facilitate discourse, have indoor and outdoor investigations, or build and present artifacts to make sense of phenomena.

The analysis table from year 1 (see Appendix B) initial analysis procedure for me to identify the extent of Ms. Spark and students' implementation of six sensemaking practices in four different focal lessons. For example, in the focal lesson 3 (which is from the Bird Unit), I associated the moments where Ms. Spark introduced students with the unit and lesson level DQ, and encouraged them to use DQB, with the SMP of phenomena-based driving questions. Similarly, in focal lesson 1, I assigned the moments where Ms. Spark and students set the norms and facilitate productive discussion about phenomena under the SMP of using discourse moves. In doing so each year, I was mindful to go back and closely examine the learning goals, figuring out statements, and storylines of each focal lesson based on the ML-PBL curriculum materials. This investigation helped me to see to what extent Ms. Spark's implementations align with the proposed curriculum material and to see if she made any modifications and adaptation to the proposed lessons.

I followed the same procedure to generate the initial analysis of Y2 (2021-2022) and Y3 (2022-2023) data. The analysis table from year 2 (see Appendix C) helped me illustrate how Ms. Spark and students engaged with the certain SMPs in the moments of 12 different focal lessons. For example, in the third focal lesson (the last lesson of the Squirrel Unit), I associated the moments where students collaborated in their small groups to create their models and artifacts as SMP of collaboration. Then, I assigned the moments where Ms. Spark and students use various discourse prompts to have productive discussion during the act outs or presentations of students' models under the SMP of using discourse. Identifying those moments and associating them with the certain SMPs became possible through the evidence statements of the observation protocol and through my definitions of each practice.

Finally, the analysis table from year 3 (see Appendix C) guided me to represent how Ms. Spark and students engaged with the variety of SMPs during the 12 focal lessons of the year. Since the focal lessons of this year were more equity and SEL-oriented ML-PBL lessons, I captured more moments on the SMPs of equity and justice-oriented instruction, as well as integrating multiple literacies in science. For example, in focal lesson 6, there were moments

where Ms. Spark facilitated an interactive read aloud with students by pausing in between the book of Lonnie Johnson and asking questions about the challenges, successes, and feelings that Lonnie Johnson engaged with as he designs prototypes of toys. I associated these exchanges and moments with SMP of integrating multiple literacies since students incorporate language literacies into their science learning experiences. Similarly, in the third focal lesson, using a critical news article, Ms. Spark and students had a critical conversation on what counts as equity and why setting equitable planting goals are critical to tackle with the issues of environmental injustices. Considering this was a critical moment where Ms. Spark and students delved into the justice-oriented phenomena and issues, I assigned these moments under the SMP of equity and justice-oriented teaching.

Besides focusing on the implementations, I was mindful to add relevant student work (their verbal and written form of work) into these analysis tables as evidence to interpret students' sensemaking experiences in these lessons, and therefore in these years. For example, as students worked on adding their questions to DQB, I added the quotations of their verbal exchanges, as well as the final versions of their DQB image to the table. As another example, I also provided students' verbal exchanges and written CER charts while working on a small group investigation to design and redesign their toy cars. These types of student work become a critical data point for me as I simultaneously work on answering RQ2, while engaging in RQ1.

More specifically, to answer the RQ2 and interpret the extent of students' sensemaking experiences, I created a guideline (rubric) by describing the indicators of student sensemaking. I recognized that capturing student sensemaking is a challenging and complex goal. Therefore, it was important for me to describe, as clearly as possible, what I mean by sensemaking experience in this study and what kinds of evidence would enable me to understand if students were making sense of phenomena by engaging with sensemaking practices. Even though this research primarily focuses on the changing patterns in Ms. Spark's implementation of sensemaking practices (to explore her developing teacher identity), it is critical for me to address if the changing patterns in her and students' practice leads to meaningful sensemaking experiences for students. In other words, my aim is also to provide a guideline and to bring evidence on to what extent implementing sensemaking practices helped to support students' sensemaking experiences. In doing that, I defined and considered four main indicators of sensemaking experience. Table 5 shows what I mean by those indicators and what kinds of data source or

evidence I used to interpret if students engaged in sensemaking experiences as they implement sensemaking practices.

Table 5. Indicators to Capture Students' Sensemaking Experiences in Science

Indicators of Sensemaking Experience	Definition/Level of the Indicator	Nature/Source of Evidence
Actively wondering and noticing phenomena	- Showing curiosity and wonder how and why identified phenomena happens - Asking further open-ended questions in relation to phenomena by making connecting to everyday life - Noticing phenomena based on the observations on nature and community	- Students' verbal and non-verbal input on what we know and what we wonder chart (DQB) - "Wonder and Notice" worksheets from observed lessons
Developing meaningful and relevant DQs in relation to phenomena	- Making references to the identified DQ, - Using their own ideas to asking open-ended questions related to DQ, - Adding questions to DQB (or Wonder Board) about the phenomena - Using and referencing information stored on the DQB	- Students' verbal and non-verbal and input on what we know and what we wonder chart - Small and big group discussions of developing and asking questions
Claim-Evidence-Reasoning (C-E-R) Cycle	- Forming accurate claims, explanations, and reasoning (CER) in multimodal tasks in relation to the science phenomena: ***Claim:*** Accurate statement in relation to phenomena and/or identified DQ ***Explanation****:* Explaining how and why the identified phenomena happens and works ***Reasoning*** (evidence-based justification): Justification of how the proposed evidence (i.e., theories, empirical data, personal stories, and experiences) describes and explains why the evidence supports the claim.	- Students' C-E-R verbal or non-verbal responses to multimodal tasks (e.g., on worksheets and charts, models, artifacts, share-outs, presentations, small and large group discussions)
Critical reflection/ consciousness on equity, justice, and community aspect of the phenomena	- Connecting the science phenomena to lived experiences, family, and community - Exploring and critiquing how the science phenomena and/or event has justice implications for environment and communities (who has harmed and why) - Designing critical solutions to prevent the environmental/human-related problems that harms especially marginalized communities and nature	- Bringing family and community connections, experiences, stories, and concerns (e.g., family and peer interviews) - Building multimodal representations (models, artifacts, share-outs) to identify, critique, and resolve the community-related, societal and/or environmental issue

In defining these indicators, I asked myself these questions: What is sensemaking and what kind of experiences do we hope for students to have? What outcomes can we expect as students meaningfully engage with sensemaking practices? What is NGSS-aligned and equity and justice-oriented science teaching and how does it look in elementary science classrooms? For example, creating a meaningful *C-E-R cycle* is a critical indicator for students to commit to and engage with science and its practices. As many communities of scientists, students also collaborate with their peers as an exercise of collective sensemaking. Students can closely examine together the visual and multiple representations of data (through diagrams, models, and graphs) to make a claim about the trends and patterns associated with climate change and the disparate environmental and societal effects on different communities. In doing so, students can investigate the data while engaging in discourse, explain and draw their own conclusions based on evidence, and eventually modify and revise claims based on new knowledge. The process of incorporating new knowledge, identifying, and critiquing critical issues surrounding the science and society, and being problem solvers within the issues of justice, equity, and fairness to undo harm is at the heart of the sensemaking experiences. Therefore, in offering these indicators, I draw from my definition of sensemaking and sensemaking practices, the features of PBL, and documents and studies focus on how equitable, sensemaking and justice-oriented science teaching environments might look like for students. For example, Patterson Williams and Gray's (2021) *(W)holistic Science Pedagogy* inspired me to address the moments of sensemaking that would also prioritize promoting critical consciousness, as well as building transformative and critical mindset towards science and science phenomena.

Overall, this second phase of the analysis is critical to answering RQ1 and RQ2 because I identify critical moments and associate them with certain sensemaking practices where students and Ms. Spark implement them. This step is also critical to identifying the moments where students engage in sensemaking experiences as they have verbal and nonverbal interactions and create a variety of work together.

Step 3 of analysis: Identifying the changing patterns in the implementation

After identifying the content of critical moments through the analysis tables (evidence trails) for each year separately, I worked on spotting the changing patterns in the use of each sensemaking practice in each year. This critical step allows me to make evidence-based arguments on the changes that Ms. Spark went through in the implementation of sensemaking

practices during each year. In other words, it allowed me to highlight changing patterns in each year as I worked to reduce data yet maintain meaning. In doing so, I kept working on the same analysis tables that I created in step 2. In this step, I added an additional row to the end of each table, so that I could record my arguments on the changing patterns (see Table 6) in each SMP.

Table 6. Example Evidence Trail of the Changing Patterns in the Implementation of Each Sensemaking Practice in Each Year

Evidence Trail (**Y2: 21-22**)	Implementation of Sensemaking Practices					
	SMP 1	SMP 2	SMP 3	SMP 4	SMP 5	SMP 6
Squirrel Unit						
Toy Unit						
Bird Unit						
Changing patterns in each practice (SQ to BR)						

For example, this additional column guided me to synthesize how Ms. Sparks' implementation evolved from Squirrel to Bird unit to work more toward an equity and justice-oriented sensemaking environment, what structures were evident to show that development, and whether students' sensemaking experiences were afforded or constrained. After synthesizing the changing patterns in each practice in each year, I generated the table of changing patterns in each year (see Appendix D) by using my arguments from the rows of "Changing patterns in each practice (SQ to BR)" from each year's analysis table. Using this table helped me to simplify core arguments and make my arguments clearer as I describe the changing patterns in the implementation of each practice in the years of 18-19, 21-22 and 22-23. This table also became a guiding step for me to identify the changes across the years as the final step in the analysis.

Step 4 of analysis: Cross-case analysis over years

As the final step of the data reduction process without losing the meaning and evidence, I conducted cross-case analysis to describe/state the overall changing patterns in Ms. Spark's implementation of sensemaking practices over the period of 2018-2023. This final step allowed me to tell the story of how Ms. Spark's journey of teaching science using sensemaking practices started in 2018, continued and evolved over the years, and reached its final version within the year of 2023. In other words, through this step, I was able to look within and across the years to compare what happened in each year, in particular, what affordances and constraints acted on the Ms. Spark's practice-level experiences.

Using the analysis from the previous step, specifically drawing from the *table of changing patterns*, I generated the final analysis table which you can see in the findings section. Table 7 below shows how I provide arguments on the implementation of each practice in each year, and how I look at the similarities, differences, and contradictions between the years through the column of *changing patterns across the years*. Through this column, I decided what core themes emerged over the years in terms of the changes in the implementation in Ms. Spark's classroom.

Table 7. Summary Table to Show the Changing Patterns in the Implementation of Practices within and Across the Years

Sensemaking Practice	Implementation in 2018-2019 (Year 1)	Implementation in 2021-2022 (Year 2)	Implementation in 2022-2023 (Year 3)	***Changing patterns across the years***
SMP1				
SMP2				
SMP3				
SMP4				
SMP5				
SMP6				

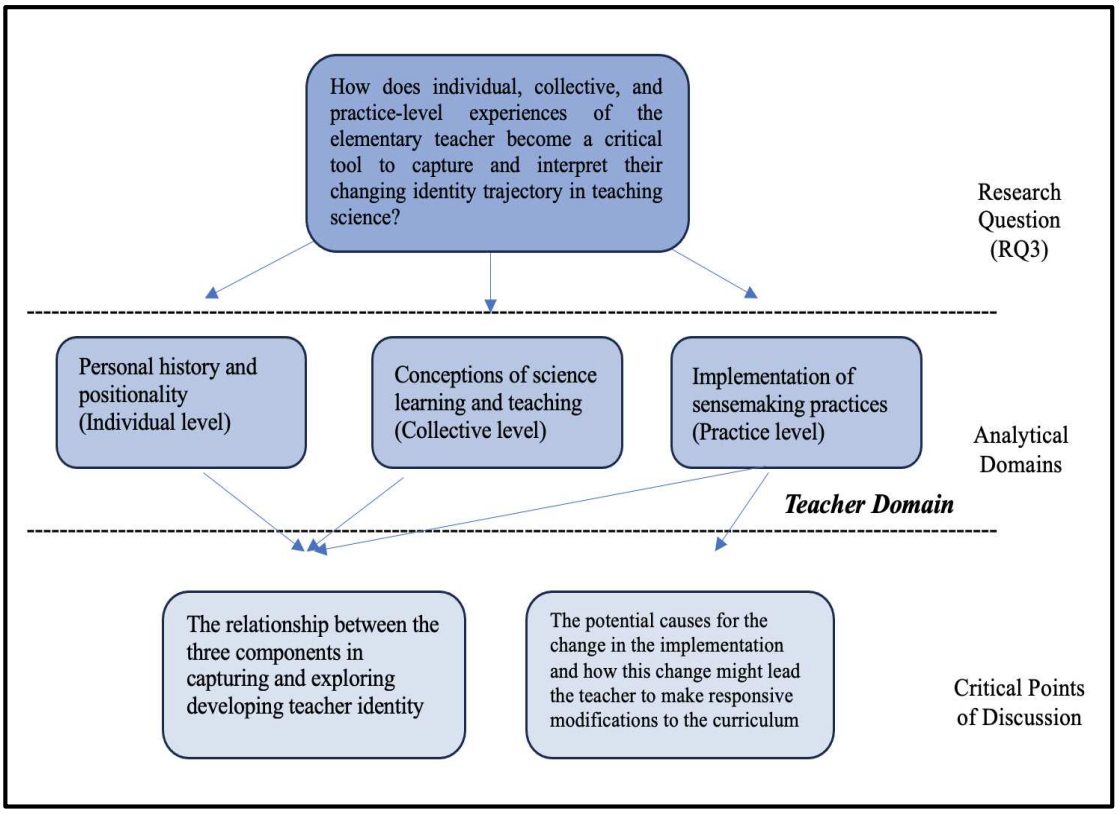
In the findings, I represented these emerging themes of change as *Snapshots* by providing detailed evidence from classrooms to illustrate how these changes in practice happen. To gather this evidence (quotation and students work), I used the analysis tables from the step 2 of the analysis and to pull evidence of critical moments in relation to the specific theme of the *Snapshot*. Most importantly, this final step of identifying changing patterns *in practice* across the years enabled me to start delving into RQ3 as I already analyzed one core component of my teacher identity framework.

Analysis of RQ3

One of the main focuses of this study is to capture and interpret the developing identity trajectory of the teachers considering the three components of identity development that I propose. Therefore, the final RQ of the study was: how does individual, collective, and practice-level experiences of the elementary teacher become a critical tool to capture and interpret their changing identity trajectory in teaching science. My initial analysis to answer RQ1 helped me start answering RQ3 since changing practice-level experiences of Ms. Spark is one of the analytical tools of the analysis. Here, I further explain how I analyze Ms. Spark's individual and

collective level experiences (remaining components of identity framework) to fully address RQ3 (see Figure 5).

Figure 5. Analysis Structure: Moving from RQ3 to Analytical Domains and Core Discussion Points



To do so, the analysis of the semi-structured interviews became the primary data source to delve into these components of the teacher's developing identity: a) Ms. Spark' personal history and positionality and b) her previous and current conceptions of ideal science learning and teaching environment considering the relationships she builds within her teaching community.

As a part of the analysis process, I initially focused on identifying Ms. Spark's personal history and positionality through her prior experiences in life and in her career. In my interviews with Ms. Spark, especially during the year 2 and 3, I spoke to her about a) who she is and what she really cares about and prioritizes in life, b) where she was born and grew up, c) where she lived and studied (elementary school to university) before she started teaching, d) why did she want to become a teacher, e) for how many years and where she taught science and other subject areas, and f) how she would identify herself considering her historical and contextual

background (in relation to her race, ethnicity, religion, gender, language etc.). Through these points of conversation, I was able to hear and learn more about who she is as a person and as a teacher, how she identifies herself within her community, what social and cultural markers she carries, and how she positions herself in life and in teaching.

Through these moments, I was able to learn more about her caring and empathetic nature and who embraces her vulnerabilities and hardships in her personal and professional life which eventually shaped her identity trajectory from the individual level. In other words, to analyze and bring evidence on Ms. Spark's individual experiences, I put together an overview of main points that would represent her positionality and life history based on her descriptions of personal life and teaching career. There was a spectrum of prior experiences, and I gathered those moments to generate themes and specify evidence (which are the quotations from Ms. Sparks' own voice) to support these themes. For example, her passion for agriculture and being a farmer constitutes a big part of her life history and her way to connect to her community. Such experiences and markers of her positionality also informed my analysis about her identity trajectory based on the individual level.

Following, in my data analysis, I focused on identifying Ms. Spark's conception of science teaching and learning. To do so, I looked at the instances where she expressed her thinking about what science is and what her ideal science teaching and learning environment look like considering the larger community context and experiences. To do so, I intentionally asked her series of questions in relation to a) her previous and current philosophy and vision in teaching science, b) the values and priorities she has in her teaching, c) how her ideal science teaching and learning environment look like and d) how she would see the role of teacher and students in such environment. Her insights to these critical points informed my analysis in generating arguments related to her conceptions of science and science teaching as another component of identity development.

In addition to these dialogues, I was also curious to delve into the underlying factors that shape Ms. Spark's previous and existing conceptions of science and science teaching. Therefore, I focused further on the questions of how and why she holds these conceptions. In these interviews, I also asked Ms. Spark to enlighten me further on her relationships with the multiple community stakeholders (students' families, school principal, curriculum coordinators, research partners, co-teachers, and colleagues). She then discussed how these members of the larger

systems might inform and affect her conceptions of science teaching and her practice itself. After these interviews in relation to her conceptions and collective systems, I put together an overview of core points on what her conceptions are and how her conceptions are shaped and informed by the larger community systems.

Finally, to identify how Ms. Spark reflected on and connected her own voice to her evolving teaching practices over the years, I had several conversations with her during Y1, Y2 and Y3 interviews. During these interviews, I was mindful to identify how Ms. Spark would connect her own personal history and conceptions of science to her changing teaching practice. In this way, Ms. Spark interpreted her own developing identity trajectory within these interviews over years. For example, in each year, Ms. Spark formally and informally reflected on a) the differences between her previous curriculum and ML-PBL , b) using each six sensemaking practices considering their affordances and challenges, d) the modifications and adaptations she did to curriculum to support students' sensemaking, e) how and why she works towards more equitable and justice-oriented approach to science and what are the rooms for development for her, and f) the professional learning experiences she had with ML-PBL team.

Through these complementary points from the interviews, I organized Ms. Spark's remarks around important claims and shifts in her conceptions and practices. For example, I identified the major shifts in her ideas related to science teaching in terms of moving towards student-centered, asset-based and sensemaking and justice-oriented science teaching by documenting what her initial idea was, how and why that idea shifted, and to what she attributed that shift.

In addition, my collaboration with Ms. Spark developed over time as I visited her classrooms. I consistently had informal and formal conversations with her about her changing conception and practice of science teaching. In doing so, I looked for and analyzed critical moments of her and students' engagement with sensemaking practices. In performing each of these steps, I kept asking myself: what was going on during the instruction, what seemed to have led to the critical moments for them to happen, what were the conditions under which they occurred, and what seemed to have happened as a result of these moments. Asking these questions provided support in delving more into (even tentative) the underlying motives and potential reasons for how and why Ms. Spark made decisions about implementing the practices and how the parts of the system helped her navigate that decision making process.

The absolute key feature of this process was its iterative nature, where I kept going back and forth between the identified key moments from her classroom. In doing so, I kept discussing with Ms. Spark how and why those key moments initiated and occurred. I shared my observations, perspectives, and interpretations of these moments with her. As we kept communicating, she also shared what she thought was happening and how she interpreted these moments. In that way, we were able to see the extent of the alignments of our interpretation. This continuous member-checking process occurred through our informal conversations before and after each class that Ms. Spark teaches, as well as through the formal interviews that we conducted.

For example, during our formal interviews in the final year (see the Appendix), I asked several questions to Ms. Spark about a) how she identifies herself as a person and as a science teacher, b) how her personal background and strong connection to farming and agriculture might connect back to her conception and practices of teaching science, and c) what is her reinterpretation of the critical moments when teaching the lessons about trees, the Lonnie Johnson story, and family interviews. By bringing these experiences and lessons back, my intention was to learn more about how she positions herself and what potential decision-making processes occurred as she reflected on herself and her teaching. Lastly, I also recently shared my core analysis points (see page 70) and emerging patterns with Ms. Spark. I asked her if my final arguments on her developing science teaching identity and trajectory aligned with what she thinks happened. She stated that my analysis aligns with her recollection of what had happened and how she would also interpret the changes she was going through. Through this acknowledgment, I was able to confidently conclude the analysis and finding sections of this study by having a consensus with Ms. Spark.

During these multiple instances of member checking, I sort of "lay my cards on the table" and positioned myself, my background, expectations, and my perspectives within the study. I facilitate a private, open, and honest conversation between me-as-person and me-as-researcher with Ms. Spark as we navigate the space of the personal to the theoretical and back again.
As Ms. Spark worked with me as a co-participant in this research endeavor, offering her insights added a critical layer of authenticity and reciprocity to a study, particularly when she gives so much of herself to researchers (Charmaz, 2014).

Overall, in the reflexive thematic analysis of RQ1, RQ2 and RQ3, I strove to identify patterns and themes with the goal of discovering, making meaning, and building new knowledge related to teacher identity work. I acknowledge that the qualitative analytic process is subjective and, therefore, an interpretive process which I think is one of the unique and beautiful aspects of such work. To that end, I was mindful and cautious to conduct skillful data analysis, while generating patterns to reduce the data while not losing meaning. I argue that interpretation of the data depends on one's theoretical and methodological standpoints that we take as a researcher along with our theoretical orientations, values, personal experiences with and knowledge of the subject matter (Lincoln & Guba, 1985; Ormston et al., 2014).

Besides, during the 2022-2023 academic year, I started to work closely with Ms. Spark and had several productive discussion sessions as we formally and informally met before and after her instruction on the focal lessons. In a way, my collaboration with Ms. Spark acted as potentially productive one-on-one coaching sessions in nature as we rethought and discussed the ways how to facilitate a lesson with a reform mindset and practices by delving into the ways of facilitating multiple modes of modeling and critical questions and discussions about cultural, and justice-oriented phenomena (Borko et al., 2008; Gibbons & Cobb, 2017). My work with Ms. Spark includes cycles of debriefing a lesson planning phase, a lesson implementation phase, and an after-lesson debrief phase (Kochmanski & Cobb, 2023). This line of collaboration and brainstorming might be one of the reasons why she improved her implementation of sensemaking practices and her mindset of cultivating critical consciousness in science in her classrooms.

One of the major affordances of these one-on-one coaching moments is that we were both mindful to consider and provide individualized, contextualized support for students as they make sense of science phenomena. Based on our discussions, Ms. Spark adjusted her work by focusing on instructional improvement goals (i.e., SEL and equity goals) that took into account students' current knowledge, practice, and classroom contexts.

Furthermore, these collaborative sessions encouraged Ms. Spark to contribute her voice to the goal-setting process as we explicitly negotiated and discussed potential ways of teaching these focal lessons through a critical lens. This aspect of one-on-one coaching work was essential because teachers are unlikely to engage in the challenging work of developing their practices if

they do not see the changes they are attempting to make as both worth pursuing and reasonable (Atteberry & Bryk, 2011).

Finally, I kept consider in what ways might my epistemological and ontological perspectives influence my data analysis and interpretation; how might I establish credibility for my data analysis procedures; In what ways can I contribute to the honesty and accuracy of my research report. To establish the credibility of the data analysis procedure, I asked another qualitative researcher to serve as a "critical friend" in, categorizing patterns, and interpreting the raw/primary data. As the two of us discussed similarities and differences in our views, I was also able to reach a new awareness of what is in the data and how the process may confirm my thinking. In addition, I was also cautious to maintain confidentiality and anonymity of the study participants.

CHAPTER 5: FINDINGS

Findings for RQ1 and RQ2

The first two research questions of the study connectedly delve into how Ms. Spark and students implement sensemaking practices in between 2018 and 2023. Following, I present findings on the changing patterns in Ms. Spark and students' implementation of changing practice by providing detailed evidence from the classrooms. In doing so, I also provide evidence on students' implementation of the practices through their verbal and non-verbal work (artifacts, models, verbal discussions etc.) that they engage with which also illustrate their level of sensemaking experiences.

Ms. Spark's practice-level experiences and students' experiences in sensemaking

The findings for this core component of the identity framework provides a space to understand how identity is, in part, recognized and developed through the actions in which the teacher chooses to engage. By participating in certain activities and practices, Ms. Spark and students come to see themselves as active and meaningful participants of the sensemaking environment.

Considering how everyday instructional practices produce shared meanings that impact teacher's identity, I analyzed how Ms. Spark's implementation of *sensemaking practices* transformed and changed over years through the end of my detailed steps of analysis. To represent the core takeaway points from the analysis, I created Table 8 below.

The table shows the main aspects of a) how Ms. Spark and students used six core sensemaking practices in each year and b) in what they shifted their implementation of each practice across the years. Following, I first address and summarize how Ms. Spark and students implemented sensemaking practices in each year consecutively to portray the details of their approach to the implementation. Then, I shift my focus on the changing patterns in their implementation across the years. In doing so, I provide detailed *Snapshots* (based on the emerging themes of the changing patterns) from each year to illustrate the changes over years

Table 8. Ms. Spark and student's implementation of sensemaking practices within and across the years

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP1: Phenomena Based Driving Questions (DQ)	- Teacher (T) started the year referring to and using DQs consistent with the materials, but inconsistently focused on connecting back to previous lessons, DQs, and students' prior knowledge and experiences - T consistently chose the phrases of: "*trying to be learning about…*" and "*trying to answer the question…*" while facilitating the discussion around the DQ during the year. - T and Students (Ss) often address both Unit and Lesson DQs together during the lessons. - T encouraged students to add their questions to DQB towards the middle and end of the year.	- T frequently referred back to the previous lessons and investigations before introducing a new DQ, so that Ss can construct the knowledge together by connecting their prior experiences to current experiences. - T's choice of wording started to shift to: "*trying to figure out…*", "*trying to explore*", "*trying to explain…"* while facilitating the discussion around the DQ and setting the learning goal of the lesson. - T made sure that they address the Unit and Lesson DQs together during the lesson; however, T intentionally let students read and introduce the DQ: "*you will teach others…*", "*you will research…*" - T and Ss often (not consistently) added and referred back to the Qs from DQB after conducting investigations. - T was quite vocal on why they conduct investigations and how these investigations would support and connect to their process of figuring out phenomena and DQ.	- The depth and quality of the discussion around the DQ peaks within and across this year. T and Ss frequently connected each lesson DQ and goal of the investigations together to support students in figuring out phenomena using variety of discourse prompts. - Ss connect back to the prior lessons and investigations in each unit. Through the discourse prompts and facilitation of the T, students bridge all the previous and current knowledge around the DQs. - T prioritizes and focuses more on asking questions to make students critically think about the issues of equity and fairness, environmental justice, and science and society starting from Squirrel unit.	- T frequently incorporated previous lessons by referring back to the prior DQs, investigations, and discussions with students. T guided Ss to link previous experiences and ideas to each other in the effort of figuring out the new phenomena - T and Ss navigated more in-depth, critical, and quality discussions around the DQ where Ss bring their cultural and intellectual resources while engaging with DQ - T's mindset started to shift from behavioral frame to sensemaking frame while introducing and addressing to the DQ - Expertise in facilitating discussion around DQ shifted from T to Ss.

Table 8 (cont'd)

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP2: Discourse Moves	- T sets norms for a meaningful and respectful discussion and discourse environment. - T starts the year using some discourse moves and as the year continues uses a variety of them, such as a) making students' ideas visible and promote discussion about DQ and Qs from the DQB, b) highlighting and connecting students' prior knowledge and experiences from their indoor and outdoor investigations, and c) guiding students as they form claims and use evidence.	- T and Ss started to use a variety of discourse prompts which focused on clarifying students' ideas and making their reasoning visible by frequently using how/why follow-ups questions. - T started to use discourse moves to collect students' ideas and represent them as new knowledge - even when students didn't express their ideas explicitly. She was able to pick students ideas up and rephrase in a way that make sense and further the discourse. - Parents who visited the classroom, particularly during the Bird Unit, also began to facilitate and became part of discourse. The parents used various discourse moves to reveal students' everyday experiences and observations about local birds as they predict and explain the features of birds.	- T and Ss set the norms of quality discourse. Unlike Y1, T introduced students to various discourse moves to express, build on, and explain ideas. Students set a baseline of what moves to use, and the quality of discourse developed by Squirrel Unit. - T used a variety of discourse moves to consistently gathering students' ideas and questions to summarize, synthesize and finally revoice them as the collective knowledge that students co-construct throughout each lesson. - As Ss develop in using variety of moves to clarify and explain their thinking, they also start connecting their everyday experiences to science as a form of evidence to support their claim without further T support. - Students contextualize discourse moves as they a) bring their family stories and cultural background to the classroom, b) connect with 1st graders through the interviews they conduct to redesign their toys, c) raise questions to promote awareness on the social, economic, and environmental aspects of phenomena.	- T and Ss continuously set the norms for a respectful and meaningful discussion in the beginning of each year. This practice developed over the years as T introduces and explains the variety of discourse moves that Ss can use as a way to collectively construct knowledge together. - The facilitators of the discourse started to shift from T to Ss and then to parents. Parents started to become community stakeholders and part of the science learning environment. - The frequency and variety of using discourse moves varied over years. The discourse started to center students' everyday experiences, cultural and family resources. - The discourse also paved the way for critical conversations around equity and justice-oriented phenomena.

Table 8 (cont'd)

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP3: Multimodal Representations (MR)	- Ss started working with different multimodal representations, such as articles, images, and videos to experience phenomena from second-hand experiences. - Ss also created multimodal representations, such as artifacts, consensus, and individual models, wonder and what I know boards, and notice and wonder charts etc.	- Starting at the end of the Squirrel Unit, T encouraged Ss to use and create equitable modes of modeling and representations. T started to prioritize what type of representations would be meaningful and relevant for students considering their previous experiences and learning needs, so they can present and explain phenomena in various ways such as through narratives, sketches, skits, drama etc. - Consensus models became a main tool especially during the Toy Unit for Ss to figure out and transition into how they can build their individual models. T also used consensus models to enrich the discourse on the critical components of models and to define concepts. - MR became a tool to connect first and second-hand experiences for students as they experience phenomena (such as using their first-hand outdoor experiences of *Sit Spots* and *Wonder Walks* in Bird Unit to identify and confirm the local birds they see through Allaboutbirds.org.	- T and Ss started to frequently use read aloud of articles and books. This became a critical MR tool in Y3 in incorporating science and literacy to leverage critical consciousness about the cultures and needs of different local and global communities. - Consensus and individual models, as well as end of unit artifacts became the core representations that students built together. T consistently reminded students to use their representations to show how they notice, predict, compare, and explain the overarching phenomena as a part of their sensemaking experience in each unit. - Unlike in Y1 and Y2, T created a buffet of resources that includes at least 20 different materials that students could use to redesign and reinvestigate their toys. This big range of materials were made of all accessible, everyday materials that students can use and test their ideas based on their imagination and curiosity.	- T and Ss start moving away from using and creating solely written forms of representations and modeling to non-written, multiple, and equitable modes of modeling and representations - MR increasingly became one of the main sources of experiencing and explaining phenomena. - MR became an essential practice to support and strengthen the collaboration in small and whole group work for students in the entire experience of sensemaking.

Table 8 (cont'd)

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP4: Integrating multiple literacies	- T did not frequently incorporate math and literacy connections to science using the materials. - T made sure to facilitate discussion when students encounter a new concept that they might not be familiar with. Through discourse, students came up with the definitions of the concepts, drawing from their prior ideas and experiences.	- T supported students in explaining core concepts (such as fair test, system, and patterns in Toy Unit) by collecting students' ideas, drawn from their observations and everyday experiences. In doing so, T moved away from just unpacking concepts related to DCI with students, but also addressing the CCC. - Ss actively worked on investigations that promote and incorporate math and literacy. Ss worked on identifying variables within fair test, using different units of analysis, and measuring distances of motion on different surfaces.	- Besides incorporating math literacy, Y3 becomes the year that the T and Ss actively use children's books and a number of articles to facilitate read aloud experiences that merges science and literacy components together especially in Squirrel and Toy Units. - T frequently navigates an interactive read-aloud discourse where she pauses many times in between the readings, shows the images from books or articles, goes through the meanings of unfamiliar notions with students, and most importantly asks numerous critical questions where students can bring their personal experiences, interests, and ideas to science phenomena. - T consistently guided students to see the connection between the texts they read and investigations they conduct.	- By Y2, the integration of math and literacy to science accelerates. By Y3, the literacy connection and integration to science peaks as T and Ss focuses their attention on a number of critical texts and read-aloud. -Over the years, T develops and enacts the practice of addressing the terms that might be unfamiliar and challenging for students. Students reveal and connect their prior ideas and experiences to define the ideas through the facilitation of T's questions. As students reach a consensus about new concepts, they compile them in their vocabulary chart.

Table 8 (cont'd)

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP5: Collaboration	- Small group work (indoor and outdoor investigations) and whole group discussions among Ss and T constituted collaboration. - Collaboration started to become an overarching SMP that involves other practices as Ss conduct and share their investigations using discourse, multimodal representations, and reflecting back on the DQ and DQB. - T started to underline the importance of using evidence to support claims as students come up with their predictions and explanations.	- The interconnection and coherence among SMPs become more visible, especially among DQ, Discourse, MR, and Collaboration through investigations - The collaboration in small group work continues to become a stronger component as students build, design and redesign solutions using evidence, and present their artifacts/models in more than one way of making sense of the phenomena. - Conducting investigations and building artifacts became central for students to experience and explain phenomena as they keep working on their claim, evidence, and reasoning (C-E-R) experiences to make sense of the phenomena.	- In each unit, T and Ss used every chance to experience the phenomena first-hand by having number of outdoor observations through sit spots and wonder walks especially in Squirrel and Bird Units. - T continues to be super vocal about the need for "evidence" to support sensemaking process in each investigation. Before all indoor and outdoor investigations, T introduces the chart or model that students will use to gather evidence based on their observations. Different from Y1 and Y2, T visibly changed the narrative of what evidence to collect and what might count as evidence to support claims as a part of students' sensemaking experience. In doing so, T encourages students to use their previous everyday experiences and family stories to take as a form of evidence to connect back to the phenomena.	- Collaboration started to constitute not only indoor small group work, but also outdoor, place-based learning experiences over the years. - Collaboration started to become a SMP that involves all the other SMPs by binding them coherently together over years. - T's dedication to encourage students in using evidence to support claims grows over the years. T consistently addressed the importance, rationale, and various forms of using evidence to reach meaningful sensemaking experiences.

Table 8 (cont'd)

Sensemaking Practices (SMP)	2018-2019 (Year 1)	2021-2022 (Year 2)	2022-2023 (Year 3)	Changes Across Years
SMP6: Working Towards Equity and Justice	- There was a lack of connection to equity and justice oriented critical conversations. In one of the lessons, T worked towards achieving SEL goal of developing students' interest in critical phenomena which superficially connected back to students lives and interest. - T was enthusiastic about bringing her life experiences and family connections to the class, allowing students to know more about her, and start building more meaningful relationships with them. Hearing more about teacher's story also encouraged Ss to bring their family experiences related to phenomena.	- T worked through identifying and responding students' struggles in writing and reading. She worked with students who prefers to use different modes of modeling by creating sketches, narrations, act outs etc., which becomes a wide array and equitable modes of exploring, expressing, explaining, and making sense of phenomena. - T and Ss more explicitly started to bring family stories and family connections to the science phenomena - T's willingness to build relationships and communicate with parents stand out. She prioritized getting to know students' families and bringing family and community connection and interest to the science classroom. She invited parents who are practicing falconry to support students' sensemaking experiences about local birds during the Bird Unit.	- T's use of variety of children's books and news articles a) to introduce students with community of scientists, engineers, and researchers from diverse backgrounds, and b) to make students realize, question, and critique the potential reasons behind environmental inequities and ways are to act towards equitable solutions. Students consider the notions of what equity and fairness might mean in the context of science and society. - Centering students' resources and promoting student-lead expertise peaked when students conducted peer interviews with 1st graders in the Toy Unit, as well as when they shared family interviews in the Bird Unit. Interviewing with peers helped students to develop critical skills and socially and emotionally connect to and collaborate with others. Conducting family interviews were essential to bridge family's historical and cultural stories, experiences, and resources to science phenomena, and to connect those different ways of knowing.	- As Y3 progressed, T prioritized asking critical questions and facilitating discussions about equity and justice, and connected phenomena by raising social, cultural, and environmental issues in science and society. - Students' use of family and peer interviews became a cornerstone towards the end of Y2. Students started to bring their cultural resources to explaining science phenomena where they can relate to other scientists and feel more interested and confident about being a part of science community. - By Y2, T's investment in including students' families as experts peaked.

Summary of the Implementation of Sensemaking Practices within Each Year

Year 1: Implementation of sensemaking practices during 2018-2019

In the 2018-2019 school year, Ms. Spark started implementing sensemaking practices (SMPs) in the context of ML-PBL for the first time. This serves as a baseline for her new journey in teaching science. In this year, she worked towards getting familiar with the curriculum materials, figuring out the rationale and learning goals of the lessons, and ways and practices to enact them. She constantly participated in professional learning (PL) sessions, which were led by ML-PBL researchers during the period of 2018-2020. Based on her interpretation of the ML-PBL content and experiences from the PL sessions, Ms. Spark started her journey of using equitable and sensemaking practices and the ML-PBL curriculum materials to teach science by moving away from traditional ways of thinking about and teaching science.

In terms of using the *Driving Questions*, Ms. Spark initiated the year by consistently going back to the previous lessons to remind students what they did and what phenomena they were trying to figure out. She was explicitly making connections to students' prior knowledge and experiences. Towards the beginning of the Toy Unit, she started to spend less time and focus on referring back to the previous lessons and experiences. Her focus shifted more on to facilitating more in-depth and meaningful discourse around the current DQ they cover. From the start to the end of Y1, Ms. Spark used the phrases of "trying to learn about…" and "trying to answer the question…" as a choice of expression while introducing the DQ and setting the learning goals for the lesson.

By the middle of the year, one of the biggest changes occur in terms of Ms. Spark and students' use of Driving Question Board (DQB) where students add their own wonderments and questions related to phenomena and DQ. While she wasn't encouraging students to bring their own questions in the beginning of the year, she frequently asked students' wonderments and questions during the Toy and Bird Unit and encourage students to put their questions to the DQB. By the end of the year, Ms. Spark spent a good amount of time on going back to students' Qs form the board and addressing them based on what students experience and learn throughout the unit. While they resolve some of them, they also keep some questions for the further investigation. Towards the end of the year, Ms. Spark and students explicitly started: a) unpacking and brainstorming more about the DQ more, b) connecting back to students' Qs and

start addressing them based on students' experiences and investigations from the unit, c) using variety of discourse prompts.

To promote the use of *Discourse Moves*, Ms. Spark first prioritized setting norms for a meaningful and respectful discussion and discourse environment. Even though she did not introduce the variety of discourse move prompts to be used, she reminded students of the general ideas and norms of listening to and acknowledging their peers' ideas and, either agree or disagree to their peers' claims about the phenomena. After going through the norms, students started to use the prompts of "*I agree with Cassie, because…*", "*I disagree with Josh, I think …*" more often. During the Squirrel Unit, Ms. Spark mainly revoiced students' ideas, encouraged them to add on each other's ideas through the prompts of agree/disagree. From the middle to the end of the year, Ms. Spark and her students added variations to the type of discourse prompts they used. Besides revoicing or adding on to each other's ideas, she actively started to support students in clarifying their thinking and making their reasoning visible. By the Bird Unit, to enrich the quality of the discourse, Ms. Spark referred frequently back to a) students' ideas and Qs from the DQB, and b) students' prior knowledge and current experiences from their small group investigations.

Ms. Spark used this first year to become familiar with how to support students in using and building various and multiple forms of expressing, experiencing, and explaining phenomena through *Multimodal Representations.* Starting from Squirrel Unit, she introduced students with how to build models and artifacts by using various multimodal representations, such as cards, texts, audio, and video resources about different prehistoric eras. For example, Ms. Spark and students used pictures from different time periods which are reflective of the survival and extinction timeline of the squirrel and stegosaurus. Using the images and text about each time interval, students work together to build a class consensus chart to figure out the timeline of when each creature was born and lived. In the Toy and the Bird Units, Ms. Spark and students started to use multimodal representations as a) a way to experience the phenomena from first and second-hand experiences, and b) evidence to support their claim in the process of figuring out the phenomena. With respect to *Integrating Multiple Literacies*, connection to science, Math, or Literacy the lessons remained superficial, mainly because of the number and the type of lessons that were observed in this first year. Nevertheless, Ms. Spark made sure to facilitate discussion when students encounter a new concept or term that they might not be familiar with. Through the

discourse prompts, students came up with a consensus in defining the concepts drawing from their previous experiences and knowledge.

Collective small group work (where students conduct investigations) and whole group discussion (where students explain their thinking by building on each other's work and ideas) constitute the *Collaboration* environment among the students and the teacher. This first year became a starting point for Ms. Spark and students to figure out how they can integrate and exercise multiple SMPs while conducting and sharing their experiences from the investigations. As students notice and observe, and predict about the phenomena, gather evidence to support their claims, and finally explaining their thinking, they frequently use discourse moves, draw from, and build multimodal representations, and eventually address the DQ and DQB. Therefore, the point of collaboration became the collection of experiences where students actively used multiple SMPs simultaneously in their pathway to sensemaking. From the Squirrel to the Bird Unit, Ms. Spark was quite vocal about reminding students about the importance of using evidence to support claims while building claims and responding back to their predictions. Her consistent scaffolding on using and gathering evidence was one of the main moves Ms. Spark used to support students to figure out phenomena as they work on their investigations, built models, noticed, and wondered, and used CER charts.

This year represented a lack of critical connection to *work towards equity and justice*. Similar to the case of integrating multiple literacies practice, due to the limited number and type of classes observed, there was a limited opportunity to capture T and Ss's involvement and investment in the implementation of this critical practice. Nevertheless, in the Bird Unit, Ms. Spark showed her enthusiasm in sharing her life experiences and family connections to science, which allowed students to get to know more about their teacher. Listening to Ms. Spark's personal history also encouraged students to bring their personal family experiences in relation to phenomena.

Year 2: Implementation of sensemaking practices during 2021-2022

This year constitutes Ms. Spark's third year of using ML-PBL curriculum and implementing sensemaking practices. Most importantly, this year was the post pandemic year when teachers and students came back to in-person modality for the first time after a year of hybrid instruction. Therefore, this year represents an additional layer of challenges in how to navigate coming back from lockdown, and how to exercise social, emotional, and collaborative

aspects of learning and teaching which is the core of Ms. Spark's approach to teaching. In addition, by this year, Ms. Spark had to pause her participation to the PL sessions (conducted by ML-PBL researchers and fellow teachers) due to her increasing workload and limited number of sub-teachers to collaborate with. Therefore, Ms. Spark's PL experiences mainly occurred between the years of 2018 and 2020, right before the pandemic hit. In addition, this is the year that I start getting to know, building relationships, and working with Ms. Spark through my classroom visits, informal conversations, and formal interviews with her.

At the start of the Squirrel Unit, Ms. Spark and her students spent a limited time to brainstorm and discuss the *Driving Questions* of the lessons. By the end of Squirrel Unit, students started to have in-depth discussions by bringing their previous experiences on indoor and outdoor investigations to address the DQ. The depth and quality of the discourse around the DQ was salient towards the end of the year. In addition, Ms. Spark intentionally let students read and introduce the DQ of the lesson and facilitate the discussion within the Toy Unit. She started to position students as the experts who construct the knowledge and facilitators who navigate the discussion. Ms. Spark and students consistently connected back to the previous lessons and investigations before delving into the new DQ. In doing so, Ms. Spark made sure to let students know how the goal of the lesson and investigation connects to the DQ that they aim to figure out. Most importantly, Ms. Spark's choice of phrases shifted from "*we're trying to learn…"* and "*we're trying to answer/respond*…" to "*we're trying to figuring out…*", "*we're trying to explore…*" and "*we're trying to explain...*". This represents an explicit and vocal shift of how Ms. Spark's mindset moves away from behavioral and product-oriented perspective to more sensemaking and process-oriented perspective.

Towards Toy Unit, Ms. Spark and students continually used variety and quality of using *Discourse Moves* and prompts by specifically raising how and why follow-up questions to make the reasoning process visible. Ms. Spark's facilitation of discourse started to get stronger as she collects students' ideas and represent them as new knowledge. Even when students didn't express their ideas explicitly, she was able to pick them up and rephrase in a way that make sense and further the discourse. The most critical change occurred in discourse when the facilitators of the discussion started to shift from teacher to students and then eventually to parents. Ms. Spark invited parents who practice falconry to the class during the Bird Unit to provide first-hand experiences and observations to students about the features, life cycles and

habitats of local birds. During the session, the parents began to facilitate and became the part of discourse. They used various discourse moves to reveal students' everyday experiences and observations about local birds as they predict and explain the features of local birds.

Towards the end of the Squirrel Unit, Ms. Spark and students worked together to decide different ways to experience and explain the phenomena. As a form of *Multimodal Representations*, students decided to build models and artifacts using equitable and multiple modes of modeling. Ms. Spark prioritized what type of representations would be meaningful and relevant for students to connect back to their previous experiences and would be responsive to students' writing and reading struggles in presenting and explaining phenomena. Therefore, students collaborate and build models in various ways through using narratives, sketches, skits, and drama. During the Toy Unit, consensus models also become a critical tool for Ms. Spark to enrich the discourse by unpacking concepts, and for students as they figure out how to build models. In the Bird Unit, multimodal representations evolved more into a tool to connect first and second-hand experiences of students together in experiencing phenomena, such as bridging outdoor experiences of *Sit Spots* and *Wonder Walks* to online sources as Allaboutbirds.org to identify and confirm the local birds students see at their school yard.

Ms. Spark facilitates discussions to guide students in defining central concepts which peaks in the Toy Unit, as students unpack the concepts of fair test, system, and patterns. In this year, Ms. Spark added a number of demonstrations right before unpacking these concepts to support *Literacy Connections*. She used these small demonstrations and investigations to create an experience-based and relevant starting point for the discussion of each concept. Students also frequently worked together on investigations which promote and incorporate Math Literacy. They consistently worked on identifying and testing variables, applying fair tests, using different units of analysis while gathering evidence, and measuring distances of motion on different surfaces. The interconnection and coherence among multiple sensemaking practices become even more visible, especially among DQ, Discourse, MR, and Collaboration through investigations. The *Collaboration* in small group work specifically became the central component for students to build, design, and redesign solutions, as well as to present and act out their artifacts in the process of sensemaking. Whole group discussions grow into a main space where Ms. Spark draw students' attention to gather and use evidence to predict and explain how and why certain phenomena occur.

In 2021-2022 school year the teacher closely works with students to figure out their challenges and struggles, as well as interests and wonders about science phenomena and how they would choose to engage with and figure out the phenomena. Acknowledging that students still transition into in person interactions due to the pandemic, Ms. Spark was mindful of what writing and reading struggles that students might experience. She did not want to lose students' interest, and but to embrace the fact that students prefer to use different modes of modeling through sketches, narrations, and act outs. These modes of expression became alternative and equitable approaches to exploring, expressing, and explaining phenomena. In addition, Ms. Spark's explicit connections and collaborations with students' parents increased this year. Her willingness to build relationships and communicate with parents stand out. She prioritized bringing family and community connection and interest to the science classroom by inviting parents to the classroom. For instance, in the bird unit she invited parents who are practicing falconry to visit and present in the class in order to support students' sensemaking experiences about local birds. Therefore, year 2 represents Ms. Spark's growing investment toward a more *equitable and justice-oriented approach* as she developed responsive practices to support students' needs and interests by using more than one approach to figure out phenomena to support students' academic and social-emotional competence. She also developed her practice to build meaningful relationships with students' families, by centering family and community as another valuable expertise and stakeholder in the science learning environment. Students and family members started holding the position of knowers and contributors visibly in this year.

Year 3: Implementation of sensemaking practices during 2022-2023

I let the teacher know that this year's focal lessons are going to be about equity and SEL goals, because I wanted to see a) how Ms. Spark engaged with the critical questions about equity, justice, and fairness in the context of environmental issues, and who gets to become a part of science society. and b) students respond to critical texts and questions in realizing, questioning, and taking actions toward inequities and injustices taking place in science and society. My informal conversations with Ms. Spark also informed and navigated the choices that she made in terms of what parts of the lesson she foregrounds and cares about. As we had critical discussion about the equity and SEL goals of each lesson prior to lesson, Ms. Spark implemented her practices taking more of a critical lens. After each lesson, Ms. Spark also shared her insights and reflections with me on how she felt navigating the conversations and how she decided to

modify some of the content in her implementation. Therefore, this year represents my building close collaboration with Ms. Spark and how she shifted her focus more into equity, SEL and justice focus by bringing local and global connections to phenomena.

The depth and quality of discussion that Ms. Spark and students had around the *Driving Questions* peaked within and across this final year. In each lesson, students start tying previous lessons to each other and set the goal of the upcoming investigations together in the process of figuring out the DQ. This year, students are the ones who become the core knowers and builders of the knowledge by bringing all the ideas and experiences together with the facilitation of Ms. Spark. Most importantly, Ms. Spark's awareness and focus on asking critical questions to make students think about the issues of equity, fairness, environmental justice, and who can become a part of science developed further starting from Squirrel Unit. In this way, students started to realize and critique more of the existing systems and components of science and society.

In the 2018-2019 school year, I observed how Ms. Spark and students went through the norms of quality discourse. Unlike the first year, when Ms. Spark introduced a variety of *Discourse Moves* and addressed why they are critical to express, build on and explain ideas. As students set a strong baseline of what moves to use, the depth of the discourse became much better in term of using and responding to various discourse prompts from the Squirrel to the Bird Unit. As students excelled in practicing a variety of moves to clarify and explain their thinking, they also started connecting their everyday experiences to science as evidence to support their claims without necessarily Ms. Spark's facilitation. Above all, in each lesson, Ms. Spark became a critical listener who confidently gathers students' ideas and questions, and used them to summarize, synthesize and then finally present their ideas as the collective knowledge that students co-construct throughout the lesson.

Reading aloud of articles and books became the raising components of *Multimodal Representations* during the year. Working on these read aloud pieces allowed students to start raising their critical consciousness in relation to the issues of equity and justice in science, as familiarize them with the backgrounds, needs and cultures of different local and global communities. In other words, besides promoting Math Literacy especially during the Toy Unit, this final year became the year that Ms. Spark and students actively used children's books and critical news articles to facilitate read aloud experiences that merges science and *Multiple Literacy Components* together, especially in Squirrel and Toy Units. In doing so, Ms. Spark

navigated an interactive read-aloud discourse where she paused many times in between the readings, showed the images from books or articles, unpacked the meanings of certain notions with students, and most importantly asked numerous critical questions where students could bring their personal experiences, interests, and ideas about explain the phenomena.

Similar to previous year, consensus, and individual models, as well as end of unit artifacts remained as the core representational pieces that students use and build together. Ms. Spark explicitly kept reminding students to use their representations as a tool to reflect on how they notice, predict, compare, and explain the overarching phenomena (as a part of their sensemaking) in each unit. Different from the previous years, Ms. Spark also created a wide array of materials and resources for students that students can use to redesign and investigate their toys. This big range of materials were made of all accessible, everyday materials that students can use and test their ideas based on their imagination and curiosity.

In terms of the *Collaboration* experiences, the frequency of students having outdoor experiences through *Sit Spots* and *Wonder Walks* to experience the phenomena first-hand increased throughout the Squirrel to Bird Unit. Ms. Spark also consistently guided students to use relevant second-hand experiences (through videos, websites, articles, images etc.) to support their first-hand experiences with an additional set of evidence as they explain the phenomena. For example, during the Squirrel Unit, students imitated squirrels jumping multiple times after watching a couple of Squirrel videos to measure and compare distances in figuring out the different structures that humans vs. Squirrels have. In the Toy Unit, MS. Spark continued to conduct a number of short demonstrations either before reading the books or students started working in their small groups. These demos contextualized and initiated meaningful discourse as students used various discourse prompts, navigated the DQ discussion, and used multiple representations such as blaster demo, video integration, and having an interactive read aloud about the phenomena. Bringing all the SMP together, Ms. Spark and students consistently interconnected many sensemaking elements together.

Ms. Spark's dedication to highlighting the need of "*evidence*" to support the sensemaking process continued in each investigation. Before all indoor and outdoor investigations, she initially introduced the chart or model that students needed to use to gather evidence based on their observations. Different from previous years, Ms. Spark visibly changed the narrative of what evidence to collect and what ideas and experiences would count as evidence to support

claims. In doing that, she encouraged students to use their previous everyday experiences and family stories to take as a form of evidence to connect back to the phenomena.

The 2022-2023 year represents the peak of implementing practices to leverage *Equity and Justice-Oriented Approach* to science teaching. First, Ms. Spark and students used a number of children's books to introduce students to a community of scientists, inventors, engineers, and researchers from diverse backgrounds. For example, in the Squirrel Unit, "*Stone Girl Bone Girl: The Story of Mary Anning*" supported students to figure out how Mary Anning discovered new fossils as a woman in the field of science and how her observations changed the natural science and history world. The article of "*Trees Grow on Money*" made students realize, question and critique a) how richer areas in the US cities have more trees and green areas, and what are the potential reasons behind those environmental inequities especially for communities with less resources, and b) the ways to raise consciousness to the issues of environmental injustices and take action towards equitable planting goals. These critical texts and discourse in the Squirrel Unit helped students to delve into the notions of what equity and fairness might mean in the context of science and society. In Toy Unit, reading "*Whoosh!: Lonnie Johnson's Super Stream of Inventions*" made students critically think about how his love of inventing surfaced in Lonnie Johnson's early life and how his passion for problem solving became the cornerstone of his career as a one of the leading African American engineers and scientists at NASA. The Lonnie Johnson story guided students to discuss and critically reflect on a) how important it is to have an ongoing interest and resilience as a scientists to keep designing and investigating until one makes sense of and resolves the problems, b) how scientists have an endless curiosity and care as they building and designs inventions for other kids, and c) the historical, social, and cultural challenges that scientists from underserved communities face along the way of working to accomplish their goals. As they had these critical conversations, students were vocal about how they relate to Lonnie Johnson's story and could see him as a role model as they also design toys for other kids and aim to become successful like him.

Centering students' resources and promoting student-lead expertise peaked when students conducted peer interviews with 1st graders in the Toy Unit, as well as when they shared family interviews in the Bird Unit. Interviewing 1st graders as they introduce their toys and receiving feedback on the design changes, helped students develop critical skills of socio-emotional learning and to connect and collaborate with their peers. In addition, conducting family

interviews were essential to bridge family's historical and cultural stories, experiences, and resources with the science phenomena, and to connect those different ways of knowing, and understanding the world around them. Students were able to learn more about how different birds can carry different special and emotional meanings for some families and cultures. While hearing students' stories, the teacher opened up about her own family and personal roots and made special connection to the certain birds and their reasons.

Changes Across the Years in the Implementation of Sensemaking Practices

Over the period of five years (between 2018 and 2023), Ms. Spark shifted her implementation of the sensemaking practices in several different ways. Drawing from the analysis across the years (see Table 8) through the various snapshots, six core themes emerge considering the critical changes in the implementation of each practice by Ms. Spark and students. The following themes capture and concretely illustrate the change in the implementation through the analysis of descriptive snapshots:

a) how Ms. Spark starts moving from behavioral frame to sensemaking frame in her introduction of and facilitation of the DQ,

b) how Ms. Spark and students change their way to set the norms and practices of having productive discourse environment,

c) how Ms. Spark starts to center using equitable modes of modeling and artifacts to leverage multiple and multimodal ways of figuring out phenomena,

d) how Ms. Spark and students start using and integrating multiple SMPs to each other in a holistic and naturally coherent manner,

e) Ms. Spark's developing dedication to make the role and different forms of "Evidence" visible to foster sensemaking experiences of students, and

f) how Ms. Spark starts prioritizing to connect students' family and cultural resources to science, and to work towards cultivating students' critical consciousness on phenomena.

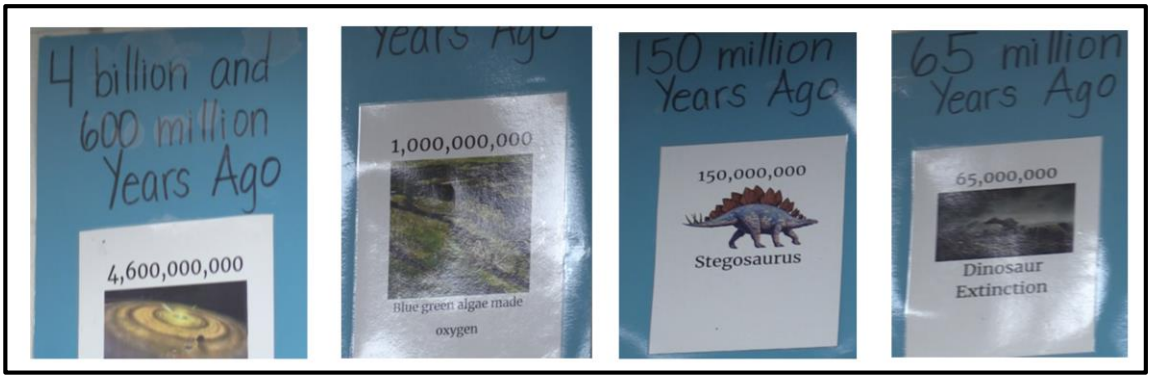
I gathered these snapshots using the real instances and critical moments/events from Ms. Spark's classroom as a complementary resource over the years. Ms. Spark's personal insights from the interviews, as well as students' work (such as artifacts, models, charts) became the supplementary evidence to spot and interpret the changes in Ms. Sparks' practice and students' sensemaking experiences over time.

Snapshot #1: Moving away from behavioral frame to sensemaking frame

The period of **2018-2019** represents the first year of Ms. Spark's implementation of sensemaking practices using ML-PBL materials. In this initial year, Ms. Spark started her instruction mainly following the prompts from the curriculum materials. Her introduction of Unit and Lesson DQs were consistent with the materials throughout the units; however, there were inconsistencies in connecting and referring back to previous lessons, DQs, and students' prior knowledge and experiences. One consistent strategy she followed was about her choice of phrases when introducing and facilitating the DQ and setting the goals of the lessons. During this first year, she consistently used the phrases of "we are trying to answer" and "we are trying to learn" while setting the learning goals and introducing the DQ.

For example, in one of lessons towards the end of Squirrel Unit, students made observations about living things and the environment using illustrations (i.e., images and posters) of prehistoric periods using timeline investigation (see Figure 6). They made claims about the periods that would support the survival of the Stegosaurus and Juramaia. The end goal was developing claims by using evidence from the timeline activity to explain how Juramaia is not the same as other organisms today and scientists have clues (fossils) to find out about the past. With that goal in her mind, Ms. Spark initiated the lesson as follows:

Figure 6. Timeline Investigation



Ms. Spark: *The last time we got together,* ***we were trying to learn*** *a little bit more about the Stegosaurus and his environment. And so, we created a timeline. I put our timeline that we created out in the hallway. I put it up here so you can kind of see it. What did you do and learn about Stegosaurus when we did this activity.*
Jaylen: *They were alive for 55 million years, so they were alive 65 million years ago...*
Maliyah: *The oxygen came before Stegosauruses and dinosaurs; they can't live without oxygen.*

Carter: *150 million years ago, Stegosaurus were born and 65 million years ago they extinct.*
Emerson*: They were born before the ice age.*
Ms. Spark: *All right, let's look at our big driving question now. Why do we see so many squirrels, but we don't see stegosauruses? We want to try to answer that second part, because we've talked about squirrels and their structures and how that helps them to survive with other in their environment, with other organisms…What do you think we're talking about to answer our lesson question today?*
Jessie: *Maybe the past of dinosaurs.*
Casen: *Maybe the trees.*
Josh: *We might learn a bit more about the plants and maybe what they ate.*
Ms. Spark: *All right. Hannah, what was your observations?*
Hannah: *Well, the dinosaurs were eating plants, so the air came up first. The dinosaurs can be last to survive, and then you have for humans.*
Ms. Spark: *All right, anybody else? Any other observations or thoughts about the timeline?*
Tyler: *They are extinct because cavemen weren't alive when dinosaurs were.*

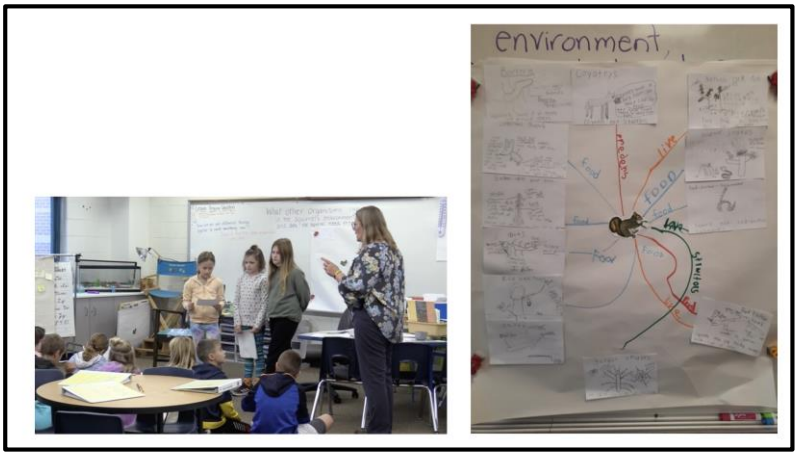
There are several interpretations we can make about this brief exchange. First, we see how Ms. Spark started to meaningfully connect the DQ to the rationale of the previous timeline investigation. Even though the discourse remained somewhat superficial, she encouraged students to connect back their previous learning experiences in the process of delving into the new driving question. Most importantly, Ms. Spark consistently used the phrases of: "*trying to be learning about…*" and "*trying to answer the question…*" while facilitating the discussion around the DQ. She used similar terminology throughout the year to set the goal and facilitate the driving questions.

During the period of **2021-2022**, Ms. Spark started to become more vocal on why students should conduct investigations and how these investigations would support and connect to their process of figuring out the phenomena and DQ. In doing so, Ms. Spark's choice of phrases started to shift into a sensemaking frame by referring to the experiences of: "*trying to figure out…*", "*trying to explore*", "*trying to explain...*" throughout the year. Ms. Spark started to move away using phrases that might be representative of a behavioral frame where students mainly aim to "trying to respond", and "trying to answer" a question by focusing on more of a product-oriented mindset, instead of critical process-oriented mindset and collective experiences.

The following snapshot took place in the beginning of the Squirrel Unit where students engaged in collaborative discussions about the behaviors of squirrels, made claims

about how the behaviors of squirrels help them survive and what other organisms play a role in meeting the need of squirrels for survival:

Figure 7. The Group Presentation and Consensus Model



Ms. Spark: *Our big driving question was what other organisms live in the squirrel's environment? We made a list of all the different organisms that we might find in a squirrels' environment. And then I gave you an article to do a little further research to try to figure out what that organism is, what its structures are, and then how you think that organism might connect to the squirrel or how it might not. Then, we're going to try to figure out does the squirrel need them to survive. Today, our lesson question today is up there. Who wants to introduce the question?*
Payton: *How do other organisms help the squirrel survive?*
Ms. Spark: *All right, we want to figure out what other organisms live with the squirrel. And then, what kind of connection they have to the squirrel. I want you to share your organism you researched about with the class, and you will teach them about your organism. You're going to teach us about the organism that you and your team researched. You're going to tell us what structures it has. How do those structures help that organism survive? And then what's the connection to the squirrel? then we're going to add it to our chart. Harper, you guys can come up here and tell us what's your organism that you're going to do? (see Figure 7)*
Harper: *We chose the cottontail rabbit. It has large eyes.*
Nina: *Cottontail rabbits have large eyes that can move all the way around, and they also have thick fur.*
Janine: *Cottontail rabbits have thick, soft fur. Cottontail rabbits have strong back legs. And our connections to the squirrel is if a squirrel is desperate enough, they will eat a rabbit.*
Nina: *It helps them because they can move all the way around so they can look for predators.*
Ms. Spark: *All right. And then the strong back legs. How does that help them?*
Janine*: They can run fast, and their thick fur helps them blend in in the wintertime okay.*
Ms. Spark: *All right. You said the connection to the squirrel is that sometimes squirrels will eat them if they're desperate. All right. There's a tub of glue over there. So, Harper,*

you can glue that on, and then you can give the other card to your friends there. Okay. While she's gluing that on Nina, what was your other organism?
Nina: *Eastern white pine trees, Needles. They have needles instead of leaves.*
Harper: *Cones hold the seeds.*
Janine: *Bark. Bark is the hard outer part of the trees, and our connection is squirrels is eating eastern pine trees for food.*
Ms. Spark: *Okay, what about the needles? How does that help them survive?*
Janine: *It can poke and like it holds the water.*
Ms. Spark: *Okay, so it holds the water. And when you said that it's pokey. So maybe it helps keep animals away or from the tree. The connection was that squirrels eat pinecones. Let's glue those on there. And then we said that you guys said that the rabbit. Sometimes the squirrels will eat rabbits, and then sometimes the or the rabbits will eat the cones. So, we're going to add a line in here to show that this is their food source (see Figure 7). So, we know that that's we don't forget that that's our connection.*

At the beginning of the Squirrel Unit, Ms. Spark introduced students to the Unit Level DQ by making sure to remind students about the important questions that they engaged with in the previous class. Even though she didn't spend much time navigating the discourse on these earlier questions or addressing students' own questions about the phenomena, she transitioned into the new DQ of the day by inviting students to raise it. She set the ground by positioning students as the experts and knowers by assigning the role of sharing and teaching others about the phenomena. Students in 9 different groups seemed involved, especially when they shared their research on their focus organisms and how those organisms would connect to the needs of squirrels' survival. Students represented their connection model and shared the structures of the organisms they worked on. Through Ms. Spark's how/why follow-up discourse prompts, students clarified and deepened their thinking and brought further explanations to the DQ.

At the end of the unit, students collectively created a model and co-construct knowledge by drawing from their everyday observations, articles they read, and videos they watched on the squirrel's connection to other organisms and their survival mechanism. Building a consensus model as representation amplified the extent of and depth of discourse and collaboration among teacher and students that shows how incorporation of multiple practices are inevitable and more meaningful in promoting the experience of sensemaking. It is also notable that during the entire class, Ms. Spark intentionally used the notion of "*trying to figure out…*" as she introduced and facilitated DQ. Later in the year, she also started using actively the phares of "*trying to explore*", "*trying to explain...", and "trying to connect…" as the components of the sensemaking process.*

The **2022-2023 school year** represents how Ms. Spark and students peaked in incorporating previous lessons by referring back to prior DQs, investigations, and discussions. Ms. Spark consistently guided students to tie their previous experiences and ideas to each other in the effort of figuring out the new phenomena. Ms. Spark and students excelled in navigating more in-depth, critical, and quality discussions around the DQ where students brought their cultural and intellectual resources while engaging and making sense of phenomena. In addition, the expertise in facilitating the discussion around DQ shifted from Ms. Spark to students over the years. The shift in Ms. Spark's mindset and actions from behavioral frame to sensemaking frame made that change possible as she altered her choice of wording and actions from *answer* and *respond* to *wonder, notice, connect, predict, explain,* and *figure out* while referring to the experiences that promote sensemaking which aligns with our definition of sensemaking.

The following excerpt highlights a lesson from the Toy Unit with the overarching phenomena of why moving toys stop, start, and change their motion in different surfaces. During the lesson, students worked toward figuring out how friction is a contact force which acts between a moving toy and the surface it is in contact with and acts against the direction of motion:

> ***Ms. Spark:*** *Our driving question is how the surfaces making of different materials affect how a toy moves. Last time, we did the balloon launch and I still have the string up there. Let's go back to that investigation first. What did we figure out about the different textures or surfaces of how it affected the way the balloon launcher moved?*
> ***Jim:*** *Sometimes the strings make it stop.*
> ***Ms. Spark:*** *Okay, so tell me more. What do you mean by that?*
> ***Jim:*** *Like it doesn't move and there's like, little fuzzy things that stop it.*
> ***Lincoln:*** *The blue string has those fuzzies and it's thicker… There's no space on between the straw and the string. So, the balloon rocket can go.*
> ***Ms. Spark:*** *Okay. Ashley, you want to build on what he said.*
> ***Ashley:*** *The blue string has a lot of friction and the other, the white yarn and the fishing string doesn't have any friction. The white yarn only has a bit. On the other two, it goes a lot faster because of how thin and how much more room they have in between the straw.*
> ***Ms. Spark:*** *All right. Harper, did you want to add to what she said?*
> ***Harper:*** *The blue one is pretty thick, because it has more strings of little strings of yarn made with it so it's way thicker. Then, it's just it doesn't give it enough space to slide, so it just stops. But then the other two, it has enough room, so it slides okay.*
> ***Ms. Spark:*** *Okay, you guys agree with what she says?*
> ***Students:*** *Yes!*
> ***Harper:*** *The fishing line is really thin, so that it goes all the way up, but then it comes back down.*

Sherry: *The blue one is way thicker than the fishing line. It's kind of hard for the air to push out. It doesn't move like as fast, as Harper said it goes back down because it's so thin. And it like comes back down, but with the blue one it doesn't have any space. So, it kind of gets stuck.*
Ms. Spark: *Okay. we said the blue yarn head is the texture is really fuzzy. What's the texture of the fishing line?*
Jazzlyn: *The texture of the fishing line is like metal.*
Ms. Spark: *Okay what would that feel like?*
Jazzlyn: *Like hard.*
Marshall: *Uh, maybe it could be like smooth.*
Ms. Spark: *Okay. we have two different textures. We had one that was you said really fuzzy and rough, and it didn't have a lot of room. And then on the fishing line, you guys agreed that it was really smooth. The straw was really smooth. So those two surfaces, when they rub, they just went up and then slid back down. So, this is what we called as friction before. Friction we talked about is a force. It's a contact force because it comes in contact, and it can slow it down. And it's the interaction of two surfaces that rub against each other. And it can change its motion. It can change the speed of it, speed it up, slow it down, change the direction. It could, make it spin and turn. Marshall?*
Marshall: *Like a car with the friction and the texture, some of the like with the thin string, it does have some friction, but it has enough friction where it will go up to the top and then it'll stop. But with the fishing line, it doesn't have a lot of friction, so it would just slide up and slide back down.*
Ms. Spark: *All right, so he's talking about the cotton string. The medium string has a little bit of friction. So, it did slow it down some but not a lot. You guys agree with that?*
Students: *Yes!*
Ms. Spark*: All right. we're going to do our own investigation today. We're going to try to explore how does friction affect our toy on different kinds of surfaces. So, if we were to get some hot wheel cars, what would be some things that you would investigate to try to explain how friction would affect the motion of a toy car?*
John: *I would push it a little bit and wheels can move with the car to itself. Start comes to a stop.*
Ms. Spark*: Okay. He's saying that you could try pushing it in different ways to see how that would affect how fast or how far it goes. Shannon, what do you think?*
Shannon: *It's going to be hard. When you put it like on a hill or something, it would go down really fast because the wheels.*
Harper: *Being the car driving down the hill. Depending on the friction is depending on the speed and direction. That's why, depending on how steep the hill is, and the friction is depends on how fast the car will go.*
Ms. Spark: *Okay. you said this is kind of like the straw and the different yarns. What surfaces could we try it out on that would be kind of like the yarn?*
Ron: *A contactable surface.*
Ms. Spark*: Like what kind?*
Ron: *A flatter surface like wood or cardboard.*
Hunter: *We could use the floor that's over there.*
Roman: *Like plastic.*

Ms. Spark: *Something plastic. Look around. What will be some other like things that we would like to try it out on. We have different textures.*
Darcy*: Like a really fuzzy carpet. Like, roll it and it would stop.*
Ms. Spark: *On a fuzzy carpet and* ***you're already making a prediction.*** *You don't think it's going to move as well.* ***Why is that?***
Darcy: *Because it's just like the straight over there. It's too fuzzy. So, the car will stop.*
Ms. Spark: *All right, so we're going to do our own investigation. We're use hot wheel cars, and I made some launchers.*
Students: *Yeah. Yay!*

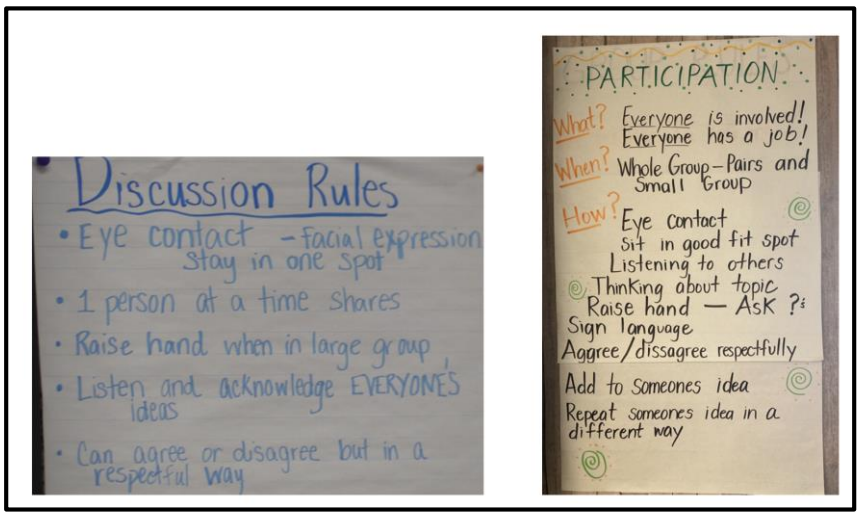
In this exchange, Ms. Spark started by asking questions to address back to the previous investigation as a way to build off how earlier and current ideas together. However, instead of Ms. Spark summarizing the previously constructed knowledge, this time students set that knowledge by bringing their insights to the teachers' discourse prompts. In doing that, Ms. Spark and students use of discourse moves peaked in terms of revoicing and rephrasing each other's ideas, bringing further explanations and rationale to their claims, building on each other's ideas, agreeing, or disagreeing to each other's ideas, and raising predictions about the motion of the toys in different possible surfaces before conducting the investigation by providing reason for their thinking. In supporting this meaningful discourse, Ms. Spark made sure to highlight what certain experiences students needed during the lesson, such as making predictions, exploring, and explaining claims to figure out the phenomena. As the school year continued, students kept hearing and being exposed to the type of experiences necessary to implement practices that support the sensemaking frames and experiences.

Snapshot #2: Setting the norms and practices to promote productive discourse

In the **2018-2019,** Ms. Spark and students started implementation of discourse by setting the norms necessary for respectful and meaningful discussions. They set principles and called them *rules* for the discussion. These principles seem to act like a classroom management tool which reflect the behavioral expectations students would have for respectful discussion. From that perspective, the way that Ms. Spark and students set the discourse norms aligned more with a behavioral frame that I referred to in the earlier snapshot. Nevertheless, these discussion rules provided students a basis for how they can show their involvement in the discussion, and how they can contribute to the discussion.

At the start of the Squirrel Unit, Ms. Spark listed their discussion rules by connecting back to the poster the class developed:

Figure 8. Discussion Norms and Rules in Year 1 and Year 3 Consecutively



> ***Ms. Spark:*** *I want to remind you our discussion rules. Our rules are right up there (see Figure 8). When someone is sharing you make sure that you use eye contact and that you're sitting still. Only one person at a time shares. You raise your hand when you want to share something, and you listen and acknowledge everybody's ideas. You can agree or you can disagree, but you need to do it in a respectful way. So, make sure that you're following our classroom rules that we agreed to. For example, you can raise your hand and add on to what Jared said in a respectful way.*

At the start of the **2022-2023**, Ms. Spark again chose to start the Unit by setting and going through the norms of quality discussion and discourse with students. Unlike the first year, there are number of changes on how she portrayed and introduced the norms of productive discourse:

> ***Ms. Spark:*** *The last time we get together, I just wanted to remind you what we wrote down to our notes and what we include to our poster (see Figure 8). We said we were going to work on one thing. What's our one thing we're going to work on?*
> ***Students:*** *Participation!*
> ***Ms. Spark:*** *We said that participation is when everyone is involved, everyone has a job, everybody has got a part, everybody is doing something. So, when we're all together or when you're working in your group, or maybe when you pair and share, and you're talking to your friends... What you can do that is making sure that you're listening and that you're listening to think about what they're talking about, so that you can either respond to what they say and there's ways that you could respond. We said if you're a little uncomfortable raising your hand, you could do this (she shows a hand gesture). Which means that you do have a connection. You agree or maybe you disagree. So, we said this was one way that you could show that you disagree (she shows another hand gesture). Then, you're nodding your head. So, I know that you're understanding what's going on. Or sometimes you can even do a thumbs up. And you could also ask questions to your friend or me, you could repeat somebody's idea, maybe in a different way. You could add to somebody's idea, say, I agree with what Easton said, but I want to add this,*

or you can disagree. We talked about how you got to do it in a respectful way so that we don't hurt other people's feelings. So, you might say, well, I understand what you were saying, but this is what I was thinking. So, although I acknowledge what he said, I did it in a way that was respectful.

Unlike the *rules* from the first year, I noticed a number of changes how Ms. Spark portrayed and decided to verbalize the *norms* of productive discourse. First, she conceptualized the process as *participation* where students can participate in various roles by using various discourse moves, such as agreeing/disagreeing, revoicing, and rephrasing ideas, and building on each other's ideas. In this way, the array and variety of the discourse prompts that the students can use increased compared to year one. In this version, students are not encouraged to follow rules for staying in the ground of discussion. Ms. Spark also acknowledges the fact that she and students come up with the principles of what, when and how to participate in discussion.

Snapshot #3: Leveraging equitable modes of modeling to make sense of phenomena

During the **first year of implementing the ML-PBL materials,** Ms. Spark started to incorporate various multimodal representations to support students' sensemaking experiences. She mainly introduced the representations, such as images, articles, video and audio resources as second-hand resources and experiences that students can use while experiencing, explaining, and finally figuring out the phenomena. Students used these resources to inform and strengthen their own multimodal representations, such as artifacts, consensus, and individual models, wonder and what I know boards, and notice and wonder charts, to express and explain their ideas in a more tangible and relevant way. In this initial year, students created their work only in the written forms of representations and modeling with the guidance of Ms. Spark.

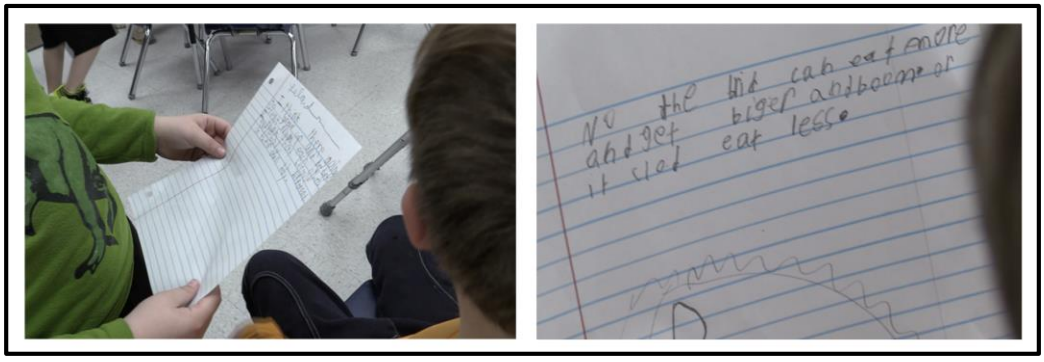
The following exchange from Bird Unit illustrates how students start investigating the phenomena of birds that are from the same family look a lot the same, but they also have differences. They watched a short video about a hawk brother and sister and analyzed the traits of each. They work towards figuring out whether brothers and sisters from the same family will have some different traits from each other using variety of multimodal texts:

Ms. Spark: *You're going to predict that how they come out of their egg and what they look like. Okay, I have this little video. It's a hawk. This is a live cam just a little bit of it one day. she's kind of fixing up her nest. They call it nest duration. So, she's just kind of fixing up her nest and you could see that she's got some eggs underneath her there.*
Melanie: *So nice! Such a cute little thing.*
Ms. Spark: *You can see she's got a few eggs. Those eggs were from previous. And she had had her eggs had hatched and she had out of the three she had two chicks that had*

hatched out of it. Two boy chicks. So, our question was will the hawks that hatched out of those eggs, will they grow up to be exactly the same, or will they be different from each other, and what your evidence is. You're going to do a quick write…
Students work on their writings around five minutes…
Ms. Spark: *Okay, finish your last sentence. This side of the room is going to find someone on this side of the room to stand and share. You're going to be face to face. You're going to read your response, and then you're going to listen to their response. So go ahead and find somebody on the other side of the room.*

Exchange from one of the pairs:

Figure 9. Joey and Carol's Exchange on Their Drawings and Explanations



Joey: *Everybody's different in their own way. I think they're going to grow up and be different from each other. Because I think that everybody's different in their own way.*
Carol: *Yeah. One bird can eat more and can get bigger, or it can be small and eat less.*
Joey: *But I don't get it.*
Carol: *Well, we have like basically the same answer.*
Joey: *So, you're so you're basically saying they're going to be different from each other.*
Carol: *Yeah. It could just eat more, and one just can eat less.*

Students started their investigation watching a short video (a live cam) of a hawk where students can see the nests of the parent and eggs. The video became a useful second-hand resource for students to observe the phenomena and build their claims using the evidence as they explain and figure out differences or similarities in the hatched eggs. From this perspective, this excerpt is also representative of Ms. Spark's focus on the importance of adding evidence to claims.

Ms. Spark encouraged students to transform their thinking into the writing form before they share their ideas with their pairs. Joey and Carol's written responses and dialogues were quite similar to other pair's work (see Figure 9). Their work shows how students mainly picked up ideas from the hawk videos without necessarily using their observations from them to support their explanations and therefore stories. In this lesson, students' sensemaking experiences were

fostered even more by bringing more than one resource (videos) as a way to experience, relate and experience phenomena. Students brought their personal experiences on spotting the differences of the local birds outdoors, and most importantly students could use different modalities (drawing, sketching, narrations, act outs) to share and explain their wide array of thoughts without sticking with the expectations of written forms of representation.

During the **2021-2022 the school year**, Ms. Spark started working with students to determine what writing and reading struggles they have and to find alternative ways to leverage multiple ways of expressions as the students explain and figure out the science phenomena. In doing that, Ms. Spark encouraged students to use equitable modes of modeling and representations as ways of cultivating their creativity and comfort in their work with others. She prioritized the type of representations that are meaningful and relevant for students and responsive to their previous experiences and learning needs. Therefore, students built their models and artifacts not only in a written form of expression, but also using narratives, sketches, skits, and drama.

In the last couple of lessons of the Squirrel Unit, students worked collaboratively in their groups by drawing sketches and performing skits to explain the overarching phenomena of squirrels' survival and stegosaurus's extinction. More specifically, with Ms. Spark guidance, students created models to explain and figure out what might cause early eutherian mammals (Juramia) to adapt and live and evolve into the Squirrel, and the stegosaurus to become extinct within the changing environment (climate, other organisms moving in and replacing food sources, predators etc.). The following excerpt represents how students built multimodal representations using verbal and non-verbal language including symbols, gestures, drawings, and skits to express and discuss their thinking, explanations towards the phenomena and DQ:

> ***Ms. Spark:*** *So, our last question today is up there our board, who wants to read it? Kate?*
> ***Kate:*** *How can we use our model to explain our thinking about what happened to the stegosaurus?*
> ***Ms. Spark:*** *Okay, in the last couple lessons, you created your models with your peers in your groups. Today you're going to share your work and explain us your group's thinking. Which group wants to start first?*

The first group presents:

Figure 10. The Moments from the Group's Skit Using Narrations and Gestures

Nina: *I'm the stegosaurus (she shows her costume).*
Bradley: *I'm also the stegosaurus.*
Sarah: *I will be the Juramia.*
Ciara: *I'm the big tree in the forest. Okay, let's start. 150 million years ago the stegosaurus came to the Earth and live in the Jurassic period.*
Nina and Bradley sit in the middle of the carpet and pretend they are eating ferns and bugs...
Bradley: *Nom nom! I can eat 200 pounds a day with my strong teeth! (He pretends to eat ferns)*
Ciara: *Until…*
Nina: *Eww… (She pretends to eat bugs)*
Ciara: *Things started to change… Stegosaurus got weaker and weaker in time, and it couldn't find any food anymore and couldn't run away from the predators. Then, the climate started to change, and they were all gone.*
Nina and Bradley: *The ladybugs are gross it is making me weak (After eating the bugs, they pretend to lay down and die).*
Ciara: *The food chain was getting smaller and that put stegosauruses down and go extinct.*
As Nina and Bradley leaves the carpet, Sarah comes in and sits in the chair (which represents a tree in the forest) …
Ciara: *Then, the Juramia was happy eating insects around the forest. She was hanging around lots of trees and it survived, because it can climb trees and it can hide and go lot of places. Juramia was walking around the forest and eating insects and ladybugs.*
Sarah: *This is yummy, I'm happy. (Sarah walks around and rubs her stomach and smiles)*
Ciara: *and Juramia had used ferns to keep warm the weather and climate was changing.*
The second group presents:
Emma: *Stegosauruses eat ferns, not grass and that means there was a lot of ferns. It was getting hot and humid. They had flat teeth to eat ferns. The stegosaurus did not have the right structures.*
Ms. Spark: *Okay, what do you mean the right structures?*
Jason: *His teeth was flat, so he couldn't eat many things.*
Ms. Spark: *Why wasn't that the right structure? How would that affect he survive or didn't survive?*
Becca: *Because it was eating ferns with his teeth and there weren't any more ferns.*

Jason: *Stegosauruses lived in the Jurassic period and ate ferns. In time, the temperature has changed, the fern stopped growing and they couldn't find enough food.*

Figure 11. The Group's Written Model and Their Verbal Representation

Becca: *Juramia need a place to hide. Juramia had a sharp tooth to chew bugs, and tail to balance, sharp claws to climb and jump fur to keep them warm.*
Ms. Spark: *Okay, so the Juramia had the right structure? Does anyone agree with them?*
All students: *Yes!*
Ms. Spark: *Okay, what was some other reasons why Juramia did surv**ive**?*
Emma: *They have better structures because they were small, and they ate bug seed with their sharp teeth. They were able to hide, and their hearing and eyes were better.*
Ms. Spark: *Okay, what about the plants?*
Jason: *They had a bunch of ferns and trees also provide shade for stegosauruses and Juramia.*
Ms. Spark: *Okay Jason, can you tell me more about the trees in there? What kind of trees were they?*
Jason: *They were oak trees.*
Ms. Spark: *Do you want to add something on that? Anara?*
Anara: *Back then, there were oak trees, pine trees, ferns and Jeremiah didn't have any nuts back then.*
Ms. Spark: *Okay, Anara said something interesting. What about the nut and after the Juramia?*
Will: *Juramia has fossils because stegosaurus ate a lot of plants and now the Juramia have survived, and they evolved and become squirrels.*
Anara: *Back then they were Juramia, but now they are squirrels!*
Ms. Spark: *Okay, let's go back to your model. Why does the stegosaurus no longer exist?*
Emma and Becca: *Because as the climate changed. Back then, it wasn't raining so much, and the sun was made the ferns grow so stegosauruses have food to eat.*
Jason: *It started to get a little bit colder. So, stegosaurus started to die, because they didn't have any fern and the Juramia stayed alive, but it adapted to the environment and back then Jeremiah started to eat bugs.*

The students in the first group (see Figure 10) creatively and meaningfully reflected on the extinction of the stegosaurus and the survival of early mammals. They used creative, realistic, and artful artifacts (hand-made costumes and representations of nature) to narrate the skits by imitating the body structure and gestures of stegosaurus, the tree fern in the forest and early mammals (Juramia). As they used drama to act out and narrate their story, they assigned different roles for each of the members in their groups. Before starting their skits, the narrator of the group, Ciara, let everyone know that the little sprinkled yellow papers represent the ladybugs, and the green cardboards represent the ferns in the forest. Meanwhile, others also introduced their roles in the skit.

After the first group's skit, members of the group 2 (see Figure 11) came to the carpet with their models to represent their extinction and survival model and story to address what happened to the stegosaurus and the Juramia in the Jurassic period. Students collaboratively sketched their model using labels and explanations to make their claims visible. Finally, they present their work together by narrating what they included in their model and by responding to Ms. Spark and their peer's follow-up questions. Especially, Ms. Spark's follow-up questions served as discourse prompts to strengthen students' explanations and make their reasoning even more visible. The equitable modes of multimodal experiences continued throughout the year and showed how multimodal representations started to become an essential practice to a) support and strengthen the collaboration in small and whole group work and b) provided a basis to have an in-depth and meaningful discourse around the overarching phenomena and DQs.

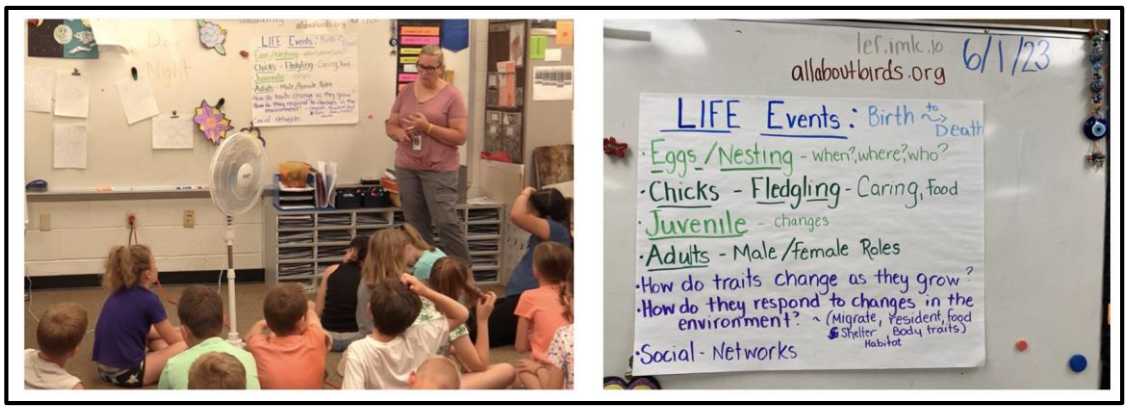
In the **final year of the implementation (2022-2023),** students worked collaboratively to build models to represent their chosen bird's life cycle at the end of Bird Unit. In doing so students draw from their outdoor observations and investigations about which stages the birds might be in, and where the chicks and juveniles are located. They also engaged with the ornithology lab, allaboutbirds.org and Audubon to figure out the changes their bird goes through throughout their lives. In this particular lesson, students built on this prior knowledge and first and second-hand experiences to build models which include a life cycle of their own design and a short story of their bird's life cycle. Following, Ms. Spark asked questions about previous lessons and experiences about the DQ, and students addressed what they started to figure out about the similarities and differences in the life cycles of their focus birds:

Ms. Spark: *Our question was how is your bird, your focus bird, how is their life cycle unique and different from other birds? You already came up with some ideas of ways that they might be similar to each other. What are the ways that, like all birds would be similar that we would probably all see on all of our life cycles?*
Emma: *Eggs, they all lay eggs.*
Mateo: *They all have to have some type of food.*
Lucas: *Building a nest.*
Jennie: *They all build some kind of nest. Most of them do build a nest and they all have feathers.*
Angel: *Water.*
Ms. Spark: *They all they all have to find some kind of water source. All right. Anything else?*
Jayden: *They all become; they all go through the stages. They start out as a baby or chick, and then they all go into like a teenager or juvenile stage.*
Ms. Spark: *What do you think are some things that are going to be different in your life cycle compared to others? So, think about your focus bird. What's your group's focus bird Lily?*
Lily: *Robin.*
Ms. Spark: *How do you think the robin's lifecycle is going to be a little bit different than, say, who's hummingbird? Okay, that's Jayden's.*
Lily: *Their food that they eat.*
Jayden: *Their size and where they live.*
Ms. Spark: *So, like their nest is going to be a different size. Where they live is going to be a different place because of their size.*
Lily: *They live in different parts of the State. Some of them will migrate out of the state. Some of them will stay here.*
Nate: *The hummingbird as their babies grows bigger, it stretches out its nest and maybe other birds don't do that.*
Wyatt: *The color of them or the wingspan.*

With the facilitation of Ms. Spark, students keep raising their observations and claims about their groups' focal bird's life cycles by discussing their life stages, habitat, social and physiological and characteristics (see Figure 12). Students drew from the knowledge they constructed through their prior outdoor and indoor investigations using multimodal resources such as audios, videos, and websites, particularly allaboutbirds.org and Audubon.org. As the discourse goes on, Ms. Spark made sure to take notes and list the claims and the questions of the students about the life events of the birds, as a form of consensus chart or model (see Figure 12). This consensus chart became a critical scaffold to strengthen students' further investigations about the birds, and help them to figure out what points to explain further for making sense of the life cycle of their birds in their models:

Ms. Spark: *All right, I just jotted down some of the things that you guys talked about. These are things to remember when you guys are working on your life cycle poster that you're trying to show your focus birds, life events from birth to death. We have eggs and nesting. When and where do they nest, and who builds the nest? What kind of food are they getting when they're babies? What kind of changes are they going through as they go from a chick to a juvenile? These are some of the points and questions that you came up in the last couple of lessons. Lindsey?*

Figure 12. Students' Discussion to Build the Consensus Chart of Birds' Life Events



Lindsey: *We have like a baby bird's nest that their mom, like, put them in a tree. And then my dog knocked the nest off, and we've been picking them. Have to pick them up a bunch and put them in the nest and the mom took care of them.*
Ms. Spark: *Do they have feathers on them?*
Lindsey: *They started to get a lot of feathers, and their colors are changing as they grow up.*
Ms. Spark: *So, at first, they didn't have a lot of feathers. And then you're saying now they're getting more and more feathers as they get older. So that's a good thing to put on your life cycle model is how is your focused bird. How does it change as it gets older and then as when it becomes an adult? Do they live in groups, or do they live just in pairs together or by themselves?*
Lindsey: *We've seen these little nests and gardens. We see them hatching everything. every day we would go out there to see the mom, but it wasn't there, and she didn't come back.*

After coming to a consensus on the list and how it will be pivotal for students to revise and strengthen their ongoing models, students continue working on their group models. They used a number of second-hand multimodal resources (such as their Chromebooks) to bring more evidence and back up their claims in their models:

Ms. Spark: *These are some questions to try to investigate as you're doing your model is how traits change as they grow. Before you start working, I want to show you this other website. It's called the Audubon.org. Let's say we're looking up Eastern Bluebird. So,*

we'll type in Eastern Bluebird and hit enter. And then if you scroll down, it gives you some more information like where their habitat is, what their food sources are, what material or something they use to build their nest. Here's some articles you can read to support your explanations. So, you're going to spend the majority of the time working on these today. You're sketching, but don't forget that you can't just draw. You got to do what?
***Pepper**: Label.*
***Tony:** Explain.*
***Ms. Spark:** You guys need to add some evidence and explanations.*

Example small group work (see Figure 13):

***Ariel:** Okay, we want to show their (Eastern Blue Bird's) life cycles (see Figure 13).*
***Becca:** You're making the mom does the work. The boy just sits around. Okay, that's actually a really good nest. The young one is child. Can we make this arrow longer?*
***Ms. Spark:** Where do they build their nests?*
***Ariel:** On trees like poles and trees.*
***Becca:** Where's the mama? We need the mom.*

Figure 13. Students' group work examples

***Elijah:** The male bird is getting ready. He's trying to attract the female, trying to show off.*
***Ariel:** What is the life cycle?*
***Cameron:** The life span. It says 6 to 10 years.*
***Elijah:** Yeah. So, if they can manage to survive six, ten years. Some die before that.*
***Ms. Spark:** Do they migrate, or do they stay here?*
***Ariel:** They migrate. They migrate southwards.*

***Cameron**: They come here in the spring and lay their eggs, raise their babies, and then take off.*
***Becca:** It's uncommon for them to breed right here.*
***Ms. Spark:** So, where does that go in here? Where does that go in their life cycle?*
***Ariel:** During the winter, they are in Mexico. So, they go down here to Mexico. Around Texas.*
***Elijah**: It says the departure dates for northern neighbors vary whether Minnesota birds and it'd be like Michigan, they can go anywhere from September, October, or November.*
***Cameron:** Yeah, to Mexico and Texas, southern, US.*

In their small groups, students kept adding to their models of the bird's life cycle by using multimodal resources. Ms. Spark closely attended to each group's work to ask follow-up clarifying questions about how to advance their models by bringing more evidence to their explanations and addressing the points they collectively raised in their consensus chart. With the spot on, detailed, and evidence-based claims and explanations (C-E-R), these models were the most nuanced, sketched form of expressions that students created over the years (see Figure 13).

In this final year, students consistently built consensus models. This multiple exposure of building collective charts and models supported students to create these high-quality individual and group work, because they constantly talked and thought more on how to build models, what components of the models should have, why using first and second-hand experiences and evidence is needed for meaningful explanations and therefore better sensemaking experiences. Using and creating multiple and equitable modes of models and representations increasingly became a critical tool for students to connect their first and second-hand experiences to each other as they make sense of the phenomena (such as using their first-hand outdoor experiences of *Sit Spots* and *Wonder Walks* in Bird Unit to identify and confirm the local birds they see. This meaningful change in the implementation also corresponded into students' models, explanations, and CER charts over years as they started to become much more detailed and sophisticated.

Snapshot #4: Increasing coherency among multiple practices

The year of **2018-2019** became the year when Ms. Spark started to engage and became familiarized with the curriculum materials and started exercising sensemaking practices to support students' experiences in sensemaking. More specifically, *collaboration* through small group investigations started to become an overarching sensemaking practice that reinforces and

involves other practices as students conduct and share their investigations using discourse, multimodal representations, and reflecting back on the DQ and DQB.

The following excerpt represents how Ms. Spark and students start engaging with and using multiple practices together (DQ, discourse, collaboration, and equity connection) by the beginning of the Toy Unit. In this lesson, students build their prototype toys and then investigate to figure out how the motion (speed, position, and direction) of their toy can change and what might cause this change. Near the end of the lesson, students reflected on their investigation by recording and explaining their observations of the pattern of their toy's motion and made sense of how different objects can have different patterns of motion.

> ***Ms. Spark:*** *Last time when we were together, our big question was how can we describe the motion of toys that we build? So, we are trying to move towards the answer to how can we design fun, moving toys that kids can build. We watched this little video of the Uganda boy, remember that? He used some materials that he just had around him. We said those maybe some recycling materials or things that were just laying around that he could easily build a toy. What did he make?*
> ***Jenna:*** *A toy car?*
> ***Ms. Spark:*** *And how did he feel when he got all done making the car?*
> ***Carter:*** *Maybe proud of himself.*
> ***Ms. Spark:*** *Yeah. He felt pretty proud of himself that he was able to make a car that actually could move. So, we're going to today we're going to make a prototype of a toy with some materials that you might just find lying around. What's a prototype? I think we talked about this last time.*
> ***Gary:*** *Like some type of device. It's something that can move.*
> ***Ms. Spark:*** *Yeah, it's design that of something that can move. And then we might be able to use that design to help us when we're going to make our own toys and our own design for our toy. So, each team chose a toy. Remind me of what toy you guys had? Emily?*
> ***Emily:*** *We had bottle rocket.*
> ***Ross:*** *We had skimmer.*
> ***Michelle:*** *The cart.*
> ***Ms. Spark:*** *Okay, you have to pick either the skimmer, the rocket, or the cart. So, when you go back to your table you're going to log into computer and you're going to go to lef.imlc.io. Go to the menu, go to third grade, go to toys. And then it has instructions for building toys. You're going to read the directions and watch the video. All the materials are over there and will help you on what you need when you are ready.*

Ms. Spark visits each small group as they continue building their toy cars. After students build their toys, she gives the directions for how they investigate the motion of their toys:

> ***Ms. Spark:*** *Okay, you guys are going to record your observations of how your toy moves. You're going to look at the speed of your toy at the beginning of its motion, the middle of it and the end of it. Like in the middle, maybe when it goes up in the air, it slows down. And then as it comes down, it might change its speed as it comes down. So, what*

direction is it going in? You can't just put one word down here. You guys are going to be describing your motion.

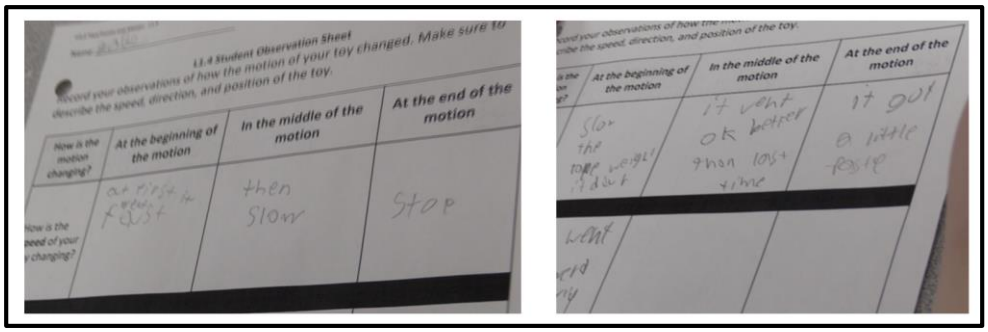
Example group work with skimmer *(see Figure 14 and Figure 15):*

Ms. Spark: *Did you got to find a way to make it move?*
Jonah: *Yeah, we make it blow like this (he uses his mouth).*
Roman: *We just need something that makes more air.*
Philip: *Like a blow dryer!*
Ms. Spark*: Do you guys want to try the blow dryer?*
Students*: Yes!*
Ms. Spark*: It's over there in the shelf.*

Figure 14. The Group's Work on Redesigning the Skimmer

In this excerpt, Ms. Spark started the lesson by raising the DQ of the lesson and provided a brief reminder of the previous lesson through their conversation on the video of a kid who builds toys in Uganda. This part of the lesson originally connected to equity and the SEL goal of the curriculum material. Even though this equity and SEL integration started a conversation on how to relate and connect with other kids, it remained superficial. Then, Ms. Spark clarified how students can use the online guidelines to build their toys following the provided curriculum materials. Students followed the instructions of how to build skimmer, cart, or bottle rocket in their small groups together (see Figure 14). Jonah, Roman and Philip's group work also illustrates how students worked collaboratively together to find and test different and effective ways to make their skimmer move faster. Nevertheless, their description and reasoning to explain the motion of their skimmer represents a superficial reflection (see Figure 15).

Figure 15. The Group's Written Work to Record Their Investigation



Even though Ms. Spark constantly worked with each group to make sure answering their questions and students were on point and following the instructions, there were missed opportunities in terms of facilitating more nuanced and in-depth discussion about students and other kids' (who are from different global contexts) previous experiences of building toys, explaining their predictions of how the toy can be built and how might it move (in terms of speed, direction, and position). Therefore, even though there were some levels of an engagement on multiple practices, Ms. Spark and students' small and whole group discussions and students' written explanations (see Figure 15) illustrates a weaker connection to sensemaking experience. In other words, Ms. Spark and students used multiple sensemaking practices by engaging with the DQ, connecting SEL and equity-oriented conversations, and using multimodal resources to strengthen the group work and collaboration; however, there wasn't harmony and coherency among these practices, and they did not necessarily connect with and support each other.

In the **following year (2021-2022)**, the interconnection and coherence among multiple practices became more visible, especially among DQ, discourse, MMR, and collaboration as students kept conducting indoor and outdoor investigations. Therefore, the collaboration in small group work continued to become a stronger component as students built, designed, and redesigned solutions using evidence, and presented their artifacts and models in more than one way of making sense of the phenomena. In addition, implementing the multiple practices together in harmony evidently support students to experience and explain phenomena. The indicators of this growing sensemaking experiences of students are the increasing quality in their small and whole group discussion, their claim, evidence, and reasoning (C-E-R) work in explaining and figuring out phenomena, as well as their inputs from the DQB and collective artifacts.

To be able to represent the coherency in using different sensemaking practices, I will provide several excepts from various moments of the lesson. The following excerpt below represents critical moments from one of the earlier lessons of the Toy Unit. I particularly chose these moments, because they provide insights on how Ms. Spark and her students meaningfully connecting the practices of: a) building *What We Wonder* and *What We Know (DQB)* boards, b) connecting family and community background (as a part of equity goal and connection) to science phenomena, c) coming to a consensus in defining unfamiliar concepts to leverage literacy skills and connections, and d) conducting individual demonstrations and collaborative small group work to define and investigate different types of forces and motion.

Ms. Spark started with inviting all students to the carpet. She introduced and facilitated a discussion on the new unit's DQ by revisiting students' family interviews in relation to the phenomena:

> ***Ms. Spark:*** *Our driving question for our unit is how we can design fun moving toys that other kids can build? Today, we will start figuring out how can we make toys that move? Earlier, we started to share some family stories about some of your parents, grandparents, and other family members. Does anyone want to remind what we have talked?*
> ***Gabriel:*** *My grandpa made different toys, like a car, when he was a kid.*
> ***Priya:*** *My dad grew up in India, he told me he was making toy planes with paper and fabric some toys that moved in different ways.*
> ***Ms. Spark:*** *Great! So, these stories might help us when we are trying to design our own toy that other kids can build. We played around with this rocket right before the break. We talked about this rocket as a system. What do I mean by a system?*
> ***Jackson:*** *System to make the rocket go.*
> ***Ms. Spark:*** *System to make the rocket go. What are the parts of the system that make the rocket go?*
> ***Sam:*** *The palm.*
> ***Kelly:*** *The tube. The tube that runs from here to the pump there.*
> ***Miles:*** *The stand that holds the rocket.*
> ***Tessa:*** *The rocket, the rocket itself and the air that goes into it.*
> ***Ms. Spark:*** *All right. You guys agree with that? So, the system has parts to it to make the rocket move and to work. When we launched it, we were trying to notice some things about how the rocket moved, and we were trying to figure out a pattern of motion. I wrote that up there, a pattern. what does that mean, a pattern of motion. How about you turn and talk to your neighbors about what you think the pattern of motion might be?*
> *Aria: Even though the rocket doesn't always shoot up the exact same, it's the same. It's going through the same cycle to make this rocket go.*
> ***Ms. Spark:*** *Okay. Did you guys hear that? So, she said even though it might not move exactly the same each time, she's saying it's kind of like a cycle. It does this a similar thing each time. Okay. Anybody want to add to what she said, Jess?*

Emmett: *We talked about that it could go like straight up and then come straight back down over and over and over again.*
Ms. Spark: *Okay, so you were talking about the direction of it that that does the same thing over and over again. Now, let's have somebody launch the air rocket and we'll see what it does this time. Garry, do you want to try it? We're going to watch to see what happens when he stomps it. Let's see what we notice about the pattern, the thing that, the cycle or what happens over and over again.*

Until this point of the conversation, we can see how Ms. Spark opened the conversation with addressing the DQ and referring back to the family interviews. As students briefly share their ideas and their family members' stories on building toys, they connect their resources to science phenomena. Following, Ms. Spark facilitated a productive discussion by raising questions on what *system* and *pattern of motion* might mean. In doing so, students first build claims drawing from their prior ideas and experiences. Then, Ms. Spark invited one of the students, Garry, to launch the air rocket couple of times, so everybody could notice and explain the repeating cycle of the motion in the rocket. Students discuss the similarities and differences between the launches of rocket in terms of its' speed, shape, and direction.

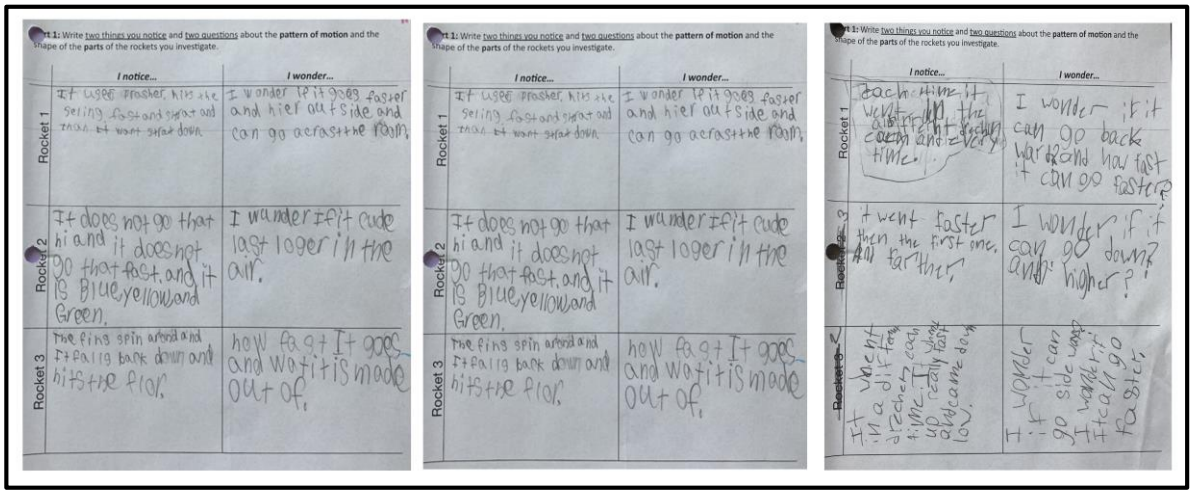
Students also consider how the pattern of motion changed based on the pressure that Garry applied to the rocket each time that he was launching. After having these initial discussion points and live demonstrations, Ms. Spark encouraged students to conduct their investigations in their small groups by using three different air rockets. Table 9 below illustrates one of the small groups works conducted by Sarah, Jack, and Gabriel as they collaborate in launching and discussing the patterns of motion of each rocket.

Table 9. Small Group Work of Sarah, Jack, and Gabriel as They Investigate the Motion of Different Sized Rocket

 ***Investigation #1: Small-sized air rocket*** *(with the facilitation of Ms. Spark)* ***Ms. Spark:*** *What are some things you notice after you launch it?* ***Sarah:*** *I noticed that whenever we squeeze it (the pump), it goes up, then it spins and flips.* ***Ms. Spark****: Okay, so it goes up kind of twirls around and comes back down. Is that what you wrote in your chart?* ***Sarah:*** *Yes!* ***Ms. Spark:*** *Did it do the same thing every time?* ***Gabriel and Jack:*** *Yes, pretty much every time.* ***Ms. Spark:*** *Okay, what about the speed? What was the speed of it?* ***Jack:*** *It wasn't very fast but, it speeded up in the air.* ***Ms. Spark:*** *Okay what do you think Sarah and Gabriel?* ***Sarah:*** *I've seen it went up and when it was coming down it was spinning a lot.* ***Ms. Spark:*** *So, it was spinning more when it was coming back down?* ***Gabriel:*** *I think so. When I was watching, I saw that it made some flips.*	 ***Investigation #2: Medium-sized air rocket*** ***Jack:*** *Maybe try to pull it back a bit?* *Sarah tries again by pulling the rocket a bit back. It makes the rocket farther.* ***Gabriel:*** *Can you try on the ground?* *Sarah puts the rocket on the ground and hits it to the ground with her hand. She takes the rocket off pull it back to it.* ***Jack:*** *Okay now you can push!* *Gabriel pushes softly on the ground first then Sarah gives some recommendations.* ***Sarah:*** *Let's have more air in it! Maybe it would make it go higher.* *Finally, Jack tests the rocket out and he does it by placing the rocket on the ground.* ***Jack:*** *It didn't go that high when you do it on the ground.* ***Sarah:*** *Can you launch it from higher?* *Jack pushes hard to the ground* ***Sarah:*** *Wow! It went really fast.* *They are writing their observations and questions on their notice/wonder charts.*	 ***Investigation #3: Large-sized air rocket*** *Sarah hits the pump twice while others observing and taking notes. They let each other to take turns. Gabriel and Jack also did launch the rocket twice. Jack was particularly hitting the pump softly first, then harder on purpose. Then Ms. Spark visits their group again.* ***Ms. Spark:*** *Did you come up with the question that you are wondering about?* ***Gabriel and Jack:*** *Yes, every time we watched it, it flipped.* ***Ms. Spark:*** *Where did it flip? In the start of if, in the middle or in the end?* ***Jack:*** *In the end when it comes back towards the ground.* ***Ms. Spark:*** *Why do you think that happen?* ***Sarah:*** *I think it's because we pushed it (launch it) very hard.* ***Gabriel:*** *My question is that if we push it in one hand will it go higher or not?*

Then, they individually worked on their notice and wonder charts to start building their own claims, predictions, and explanations in relation to the phenomena (see Figure 16 below).

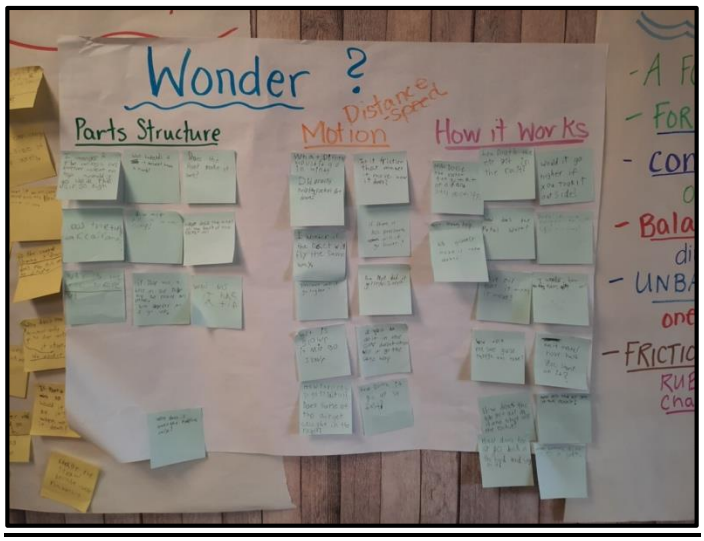
Figure 16. Sarah, Gabriel, and Jack's Individual Work



Finally, after each group completed their investigation, Ms. Spark invited everyone back to the carpet to have whole group discussion and reflection:

> ***Ms. Spark:*** *What are some things that you noticed, maybe that were different about the ways that these rockets moved, or maybe some things that made them similar to each other?*
> ***Norah:*** *The medium rocket, like it went down. Like it hit the ceiling and then twisted while going down it.*
> ***Ms. Spark****: Okay, is that the same as the other rockets or different?*
> ***Norah:*** *It was like the same with the other rockets.*
> ***Sam:*** *I asked this question for the little rocket. If it was metal instead of foam, will it move up?*
> ***Ms. Spark****: You want to know if you change the material of the rocket, would it change the way it moves? So, he said it was made out of foam. He said if it was made out of something different, like metal, would it change the way it moves? Would it still go up as high? He's wondering.*
> ***Kason:*** *I noticed these rockets have different shapes, because that one has a point on the end of it and the other two are flat.*
> ***Ms. Spark:*** *All right. So that's something that's different is that one rocket has a point, and these other ones are flat on the top. Okay. So, we also asked some questions last time. I posted all our questions on the wonder board (DQB) back there (Fig. 17). Let me just read a few of those questions that we had. Maybe you're thinking of some more questions that you're wondering about right now after your investigation.*

Figure 17. The Wonder Board (DQB) of the Toy Unit



> ***Ms. Spark:*** *We kind of grouped them up to ones that were about the structure of it. We talked about the wings on the on the rocket itself. Somebody asked, does the point make it go farther? Why does it have a tip? Then, if there was a hole in the tube, what would happen to the rocket? Would it change the way it moves? And then we had some about distance and speed, the motion of it. Is it friction that makes it move, and how does friction make it move? Some of you are already starting to think about the answer is to that. So, those are just a few of the questions that we had about the rocket, and we can add some more questions based on what you wonder. We can also start answer some of these questions after today's work and you can add your notes to our what we know chart…*

This excepts from the lesson illustrates how Ms. Spark and student engaged in a) in-depth discourse on DQ and DQB (see Figure 17), and family interviews, b) unpacking the concepts of system and pattern of motion through first-hand experiences of launching air-rocket as a demo, c) working in small groups to reveal their noticing and wonderings in relation to the overarching phenomena as a part of sensemaking experience. More specifically, the demonstration of Garry launched an air rocket become the supplementary point to leverage relevant and evidence-based discourse. Ms. Spark used this prior experience and discourse to unpack the two new concepts (*a system* and *pattern of motion*) as a way to leverage literacy skills and way to foster student investigation and collaboration to describe, interpret and explain the changing pattern of motion in different air rockets. Students left the class start figuring out the similarities and differences in the direction, speed, and the motion of their different toys as they observe some go faster, some might go slower based on how we hard and soft they launch them. Through this experience, they

figured out what parts they need to build their toy as a system and what they need consider in designing their own toy to support its motion. This overall sensemaking experience become possible as Ms. Spark and students advanced their awareness in using multiple practices together in a way that they build on and feed each other.

In the **final year of implementation (2022-2023)**, Ms. Spark and students' use of multiple sensemaking practices reached its peak. More specifically, Ms. Spark not only facilitated instruction by using DQ, Discourse, MR, and collaboration together as she did in the previous years, she also incorporated multiple literacies and equity and SEL focus to implementation. Besides incorporating Math literacy, Ms. Spark and students actively used children's books and several news articles to facilitate read aloud experiences that merges science and language literacy components together especially in the Squirrel and Toy Units.

In the following exchange, Ms. Spark and students read a book through interactive read aloud about one of the most successful female paleontologists, Mary Anning, and her discovery of Jurassic-period fossils. To support their reading and discussions, they also watched a video of *Great Minds: Mary Anning* (see Figure 19). They used the story of Mary Anning to brainstorm how they could find more information about squirrels or Jurassic-period fossils. Students also started figuring out that some of the fossils to make claims about the climates of prehistoric times were discovered by citizens, not by scientists. Students started realizing they can also ask questions that are important to them and figure out the answers to these questions that interest them and contribute to science. In that way, they started building self-awareness (as a part of SEL experience) and they were intentional in fostering and extending their sensemaking experiences:

> ***Ms. Spark:*** *We don't really read stories too often, but this one's a really good one. I think you'll like it. And it will help us to figure out this question of where have scientists and other citizens found fossils from the Jurassic period? You were thinking of a movie? Apparently Jurassic Park. We've been talking about why we see so many squirrels, but we don't see stegosauruses. Earlier, we figured out that if we find a fossil that will help us to gather evidence about what it was like back then during the Jurassic period, and then what other organisms will live there and maybe what happened to them over time. So, this is a story. It's called Stone girl, Bone Girl, and it's a story about a girl named Mary Anning, and she's from, it's called Lyme Regis. I put a picture up on the screen so you could kind of see what it looks like.*
> ***Ms. Spark:*** *I'll show you on the globe where it where it's where she's at (See Figure 18). So, we're right here. Here's Michigan, the United States. Over here across the ocean right here is where Mary Anning lived and grew up. Here she was over here.*

Ben: *It's like one ocean away.*
Dawn: *So Atlantic?*
Ms. Spark: *Yep. Cross the Atlantic Ocean. So that kind of gives you a little bit of an idea of where she's from. If you look at this cover here, what do you notice about the cover? What do you think this book is going to be about?*

Figure 18. Moments from the Read-Aloud of the Book

Lucas: *I think it's about, um, how she finds fossil in her homeland.*
Ms. Spark: *Okay and why do you say that?*
Lucas: *Because all those dinosaurs look like it's like a bunch of rhinos. And most of them kind of look like they're in the dark.*
Nolan: *Um, it's like about dinosaurs and fossils.*
Ms. Spark: *Okay. Dinosaurs and fossils. What do you think, Stone girl, Bone girl is* ***going to mean****? Lincoln?*
Lincoln: *She might find like bones or fossils from the dinosaurs and stone.*
Ms. Spark: *Okay, let's read. When Mary Anning was a baby, she was struck by lightning. I know it's kind of crazy, isn't it?*
June: *How is she not dead?*
Ms. Spark: *Sometimes people can survive, and she did it. Was it split a huge elm tree and threw Mary right out of her nurse's arms. Her father was in his carpenter's shop when he heard the terrible news. He dropped his hammer and ran through the stormy streets of Lyme Regis. Gently, he lifted the limp body of his little daughter, and his tears flowed like rain. But then an extraordinary thing happened. Mary Anning slowly opened her eyes. She reached out a tiny hand and touched the amazing face of her father, and the little girl began to smile. It was then that her father realized that Mary Anning was going to be no ordinary girl. It's pretty extraordinary, isn't it? How do you think the dad felt when he heard the terrible news?*
Micah: *Upset.*
River: *Sad.*
Arthur: *Scared. He thought that he was going to lose his daughter.*
Ms. Spark: *Mary grew into a clever girl. A mind as quick as lightning, her mother teased. Mary had few friends, except for her father, who she adored. She called him Pepper because of his speckled beard. One Saturday, Pepper closed his workshop early. He took Barry down to the cliffs by the crashing sea. She held tightly to his hand because she knew how dangerous it could be. So, I want you to think about. In that picture there you can see the cliffs and then the sea and all the rocks and stuff by the sea. Why do you think she held on to her dad's hands so carefully?*

Barry: *It is an uphill, so it's dangerous.*
Ms. Spark*: The clay cliffs at Lyme Regis are soft as melting chocolate. Mary had sometimes seen huge slabs of land slipping and tumbling into the beach below. How many of you been up in the U.P. and you've gone to the pictured rocks?*
Jessica: *Me and my mom have!*
Colter: *I've been there with my family!*
Ms. Spark*: You can probably connect to that, because sometimes what happens on the pictured rocks next to the lake. What happens to them?*
Colter*: Some of the rocks might fall.*
Ms. Spark*: Yes, so they don't let you get real super close to the cliffs because they don't want you to fall off of it… Pepper knew a place, he said, where half a farmhouse sat balanced on the cliff's edge. He and his quarryman friend had peered over and seen the remains of the kitchen and even the garden gate. And then the rocks below. All right, how many of you found something that you were super curious about? You didn't really know what it was, but it just is, like, really fascinating and curious. Aria?*
Aria: *One time I found out around my house, there's like something dig and my sister, when we're trying to get it out. We didn't know what it was. It maybe was like a fossil or something.*
Darcy: *I found a tooth.*
Ms. Spark: *You did? There's something very curious about that. What about you, Jordan?*
Jordan: *I found it, so my dog did. I don't know how she got. She was playing with the mole, and I didn't know how she even got it.*
Roman: *I found a kind of look like a like a T shaped kind of bone. Okay, like a tooth. Coming out of the school.*
Ms. Spark*: All right. River, what about you?*
River: *I was digging in my backyard, and I found like, this rock. It was big on the bottom, and it had this thing, and it was really pointy. I don't know what it was.*
Ms. Spark*: All right, so you can connect to Mary on how she was super curious exploring things, like you guys…That night, Mary couldn't sleep. Her head swirled with all the thoughts like a twisting golden stone. The cliffs are full of treasures, she whispered over and over again… Let's think about, first of all, about Mary Anning. What kind of girl do you think she is? Like, if you were to describe her, what would you say?*
Jordan: *Curious girl.*
Colter: *Unique.*
Amirah: *Very outdoorsy, and adventurous.*
Ms. Spark: *What kinds of things did she do that made her kind of unique or curious?*
Lincoln: *She like discovering fossils.*
Arthur: *She did something unique and different, she discovered really important fossils.*
Ms. Spark*: All right, so our question was, where is scientists and other citizens? Citizens are ordinary people like us. They find fossils from the Jurassic period. So, where did Mary Anning find hers?*
Ben: *Mountains?*
Dawn *The cliffs.*
Lucas: *It could be under the beach.*

***Ms. Spark**: Where do you find fossils at? We're just ordinary people. Where do we find fossils at?*
***Ashley:** Sandbox.*
***Jake:** Muddy backyard.*
***Barry:** In Myrtle Beach. I found a bunch of fossils.*
***Jessica:** In the hills.*
***Amirah:** Um, mostly I've found them in my driveway. But one time, when I went to a beach, I found a thing that looked like a snail would be in. the snail or the gastropod shell.*
***Arthur:** I found like a skeleton on the in the water.*
***Ms. Spark**: Okay. So, we can say we all connect to Mary Anning's experiences as scientist. That's very cool. She was one of those women scientists. Do we have women scientists today?*
***Students**: Yes!*
***Ms. Spark**: Do you think there was a lot of them long ago?*
***Amirah:** Maybe.*
***Ben:** A little bit of boy scientists, too.*
***Ms. Spark**: Yes, Now, before we go, I got a short little video about Mary Anning and fossils that you can watch about her.*

In this excerpt, there are several important points to highlight. First, unlike the years of 2018-2019 and 2021-2022, Ms. Spark navigated a sophisticated interactive read-aloud discourse where she pauses many times in between the readings, referring to the images from the books and video, uses the globe so students can make connections of where Mary Anning is from, discusses the meanings of unfamiliar notions with students, and most importantly asks numerous critical questions where students can bring their personal experiences, interests, and ideas to connect with and make sense of science phenomena. Second, Ms. Spark's use of discourse moves is maximized as she gathers students' ideas and questions to summarize, synthesize, and finally revoice them as the collective knowledge that students co-construct throughout each lesson.

Finally, different from earlier years, Ms. Spark frequently supported students in bringing their own personal and family experiences to science phenomena (such as their experiences in the UP and other parts of Michigan in spotting fossils) and connecting with the scientists. She made sure to ask questions about the experiences, characteristics, and feelings of Marry Anning as a young child and growing scientist. By watching the video of Mary Anning, the class further discussed how she spent her life looking at the world around her, reading, asking questions, and learning everything she could about science (see Figure 18). In that way, students started to connect and emphasize with one of the earliest female citizen scientists, because they also use

practices of science as they wonder and question about the world around them and investigate those questions to figure out how and why the phenomena occur.

Snapshot #5: Making significance and different forms of "evidence" visible

One of the salient points about Ms. Spark's approach was her consistent and growing dedication of encouraging students to use evidence as they work with their peers, as well as express and explain their thinking. **Beginning from the first year**, Ms. Spark started to emphasize what might count as evidence, the importance of using evidence, and how to use evidence to support claims to back up predictions and explanations. Even though I did not specify using *evidence* as a central sensemaking practice, for Ms. Spark it was evident that evidence was one of the core practices she used implementation.

For example, in the following lesson, students go through various images and videos of Hawks to show and describe the similarities and differences in two sibling hawks. Students analyze the photos and the video cam and discuss if the hawks' differences in traits could help or hinder their chances of thriving when compared with the other. The following brief excerpt from this lesson illustrates how Ms. Spark emphasized and encouraged students to make their arguments sounder and evidence-based to make their reasoning more visible:

> ***Ms. Spark: You're going to predict*** *that how the hawks come out of their egg and what they look like. Okay, I have this little* ***video about the hawk****. This is a live cam just a little bit of it one day. She's kind of fixing up her nest. They call it nest duration. You know, like you restore something. So, she's just kind of fixing up her nest and you could see that she's got some eggs underneath her there.*
> ***Melanie:*** *So nice! Such a cute little thing.*
> ***Ms. Spark:*** *You can see she's got a few eggs. Those eggs were from previous. And she had had her eggs had hatched and she had out of the three she had two chicks that had hatched out of it. Two boy chicks.* ***So, our question was that will the hawks that hatched out of those eggs, will they grow up to be exactly the same, or will they be different from each other, and what your evidence is.*** *You're going to do a quick write. I'm going to give you about five minutes. You just need to write your* ***response and then give me some evidence to support your answer****. So, five minutes to write down your thoughts about will you pick the hawks that hatch grow up to be exactly the same or you think they're going to be different?*

Towards the end of the first year, Ms. Spark intentionally foregrounded students' experiences from their indoor and outdoor investigations as a way to gather evidence. Using the evidence from their group work, students were able to develop more meaningful and relevant explanations in their small and whole group discussions.

In the next school **year (2021-2022)**, conducting investigations through collaborative small and whole group work continued to become the main venue of gathering and incorporating evidence. As students built, designed, and redesigned solutions for their models and artifacts, and as they took wonder walks to identify and explain the traits and survival mechanism of squirrels and birds, they constantly collected and used evidence. The following example from the Bird Unit shows how students conduct outdoor investigations around their school yard to identify and gather evidence about the local birds from all different stages. Throughout the lesson, students asked questions and collected evidence/data about the development of the birds around their neighborhood. They worked towards figuring out how and why the local birds might have similar and different traits, which include their life cycles:

> ***Ms. Spark:*** *Now we are outside, we are going to try to look for some evidence of maybe some either some chicks, juveniles, or adults. We'll see if we can figure out what exactly they are, if they are chicks, if they're juveniles or teenagers or if they're adults, and see what kind of life stage they're at. So, what evidence are you looking for?*
> ***Kelly:*** *All three steps.*
> ***Ms. Spark:*** *All right, so we're looking for the stages of the birds. We're trying to figure out if there is evidence of any baby chicks. Maybe, some eggs or nests or maybe juveniles and see if we can tell the difference between the juveniles and adults.*
> ***Sergio:*** *We've just seen one, it kind of looks like so small.*
> ***Sarah:*** *Oh, that one is an adult.*
> ***Ms. Spark:*** *How do you know it's an adult?*
> ***Sarah:*** *It's so big.*
> ***Ms. Spark****: Okay. What would be some other ways or evidence to know that maybe it's an adult? What do you think of the difference between a juvenile and adult would be?*
> ***Larry:*** *Different colors and feathers.*
> ***Justin:*** *Maybe like how it can fly.*
> ***Miles:*** *I think the crow is right there.*
> ***Ms. Spark****: What are they doing?*
> ***Miles:*** *Trying to protect their nest.*
> ***Kayla:*** *Maybe calling each other.*
> ***Ms. Spark****: Do you think it's an adult juvenile baby?*
> ***Sarah:*** *It looks like an adult. It looks like it's pretty good size.*
> ***Ms. Spark:*** *Let's talk about what evidence we gather while we're out here. What we did figure out if we see signs of chicks, juveniles, adults. What were some of the things that we saw?*
> ***Harper:*** *When you guys were looking over there, I saw a bird going really fast over there, I know it looked smaller. I think it was Juvenile.*
> ***Perry:*** *We saw a white bird over there, it was very big, probably an adult.*
> ***Sean:*** *I saw two crows flying and going over trees. They were kind of crawling back and forth.*

Ms. Spark: *What do you think? Do you think those were adults? Juveniles? Chicks. What do you think?*
Sean: *They're juveniles?*
Ms. Spark*: Why do you say that, Sean?*
Sean: *Maybe looks like the one was adult and the other one was juvenile. The one was a lot smaller than the other one.*
Ms. Spark: *All right. Now, I'm going to give you a sticky note. I want you to write one question you have for our DQB about the stages, the juvenile, the adult. When you have your question and bring it to me… Okay, here's some questions I want to just repeat. Kendall says, "we didn't see evidence of eggs because they would probably build their nests somewhere where we wouldn't be able to see them.". Payton says "Our chicks hatching in late spring or early spring. How do you tell between the juveniles and the adults and the chicks?". Another one is "Does the juvenile have different father feathers than the adults?", "How do you tell if the if it's a female so we can help her?", "Does a juvenile have different color pattern than the adult?" and "Are some chicks born in the winter out in the while?" So how could we gather evidence to answer some of these questions?*
Nina: *We could go to allaboutbirds.org.*
Sarah*: We can look their feather patterns.*
Ms. Spark: *Okay. You guys agree with that? We could go to all about birds maybe compare like the juvenile to the adult and then look at their feather patterns… Next time we're going to do we're going to do a little more digging, see if we can find some evidence to answer your questions.*

This brief experience shows how students were exceptionally vocal about how they needed to gather and use evidence to support their statements and predictions about the local birds' life stages. As they went outside, they were able to use those first-hand observations as a form of evidence to compare the birds and consider clues (evidence) as to their stages (chick, juvenile, adult). They constantly thought about what evidence might support their thinking and where they could come up with the evidence. As Ms. Spark continuously asked questions about the evidence that focused and also transformed into students' language within their claims and questions for the DQB.

Within this growing awareness of using evidence, the quality of discourse increased since students automatically brought evidence to explain their thinking, drawing from their previous experiences and indoor/outdoor investigations. In addition, students inherently started to bring evidence to support their claims made during discussions and used evidence to support their claim, evidence, and reasoning (C-E-R) charts within their individual and group work over this year which is one of the core indicators of their growing sensemaking experiences.

In the **2022-2023 school year**, Ms. Spark, and students' focus on using evidence peaked as a central component to support sensemaking experiences. Especially in the beginning of the year, Ms. Spark clearly identifies the definition and significance of using evidence. She also illustrated how students can write about and verbalize their use of evidence in supporting their claims. For example, in the beginning of the Squirrel Unit, students engaged with the DQ of how a squirrel jumps so far. To delve into the question, they engaged in a jumping contest (measuring) to see how far they can jump and compared their jumps to a squirrel's. They analyzed the squirrel's skeleton and made claims about its structure and how far it jumps. They also worked towards making sense of how squirrels can jump so far because of their skeletal structure, long body and tail, springy back legs, and light bones. The following except provides a glimpse of that lesson where students have a discussion as they watch videos of squirrel and humans jump before they conduct their jumping contest:

> ***Ms. Spark:*** *All right, so when you go to your seat, at the bottom of your paper that you will make your plan. Down here, you're going to write a claim of how a squirrel balances. And then you're also going to include evidence to support that. You might say something like, I heard some of you say that I think it was Tammy. Tammy said squirrels use their tail side to side to help balance. And he said that he knows this is true because she watched a video of a squirrel doing this. You might also use the evidence of crossing the pool noodle because you use your arms just like a squirrel would use his tail. That's the evidence that supports your statement. And then you're going to also include how does this help them survive? Why is balancing important for a squirrel to survive.*
>
> ***After students work on their plan and C-E-R statements:***
>
> ***Ms. Spark:*** *All right, let's continue. First, let's remember our big driving question. We're talking about squirrels' structures and how they're unique and important to a squirrel survival. We talked about their tail, how it helps them balance their claws up and climb. We talked how they shift their weight, use their body weight. Now, we're going to focus on how a squirrel jumps so far. Think about what we figured out so far about squirrel structures. What do you think your prediction is? How do you think a squirrel can jump so far?*
> ***Lily:*** *They use their feet to grip and then jump.*
> ***Ginny:*** *That their legs might be like a cricket, but a lot bigger so they can jump farther.*
> ***Ms. Spark:*** *Okay. Nice comparison! You're talking about like crickets there. They can jump really far, and they can you explain how the crickets use their legs?*
> ***Ginny:*** *They're really big and they like, push up.*
> ***Ms. Spark:*** *So, their legs are really big or long. And she says they kind of bend them and then push off from their kind of long spring like a spring.*
> ***Cameron:*** *I think the squirrels like a kangaroo, so you might think like a cricket.*

Ms. Spark: *All right. So, kind of like how Ginny compared to like a spring kind of compresses and then shoots up.*
Dave: *He stands there and pushes his weight on the branch and then runs and then jumps and the branch goes up with him and then he jumps high.*
Ms. Spark: *All right. So, he added a little bit more onto it. He says maybe they do a little run and then do the kind of crouch thing and then shoot off from there. What would be some ways or evidence for us to figure out how squirrel jumps so far?*
Lonnie: *We could watch some videos.*
Pearl: *We can go outside and look for them.*
Sally*: Watch them jumping tree to tree. We've seen a few of them. We did see one.*
John: *We can use binoculars.*
Ms. Spark: *These would be some ways that we could figure out how a squirrel jumps so far.*

After explaining the ways of including evidence to their writings and how important to bring evidence to their claims and plans, Ms. Spark continued to facilitate a brief discussion on how the squirrel can jump so far. In doing so, she encouraged students to make predictions and as they did, students started to provide analogies to the squirrel evidence as a form of evidence drawn from their prior observations. Ms. Spark acknowledged those analogies and prior experiences as a form of evidence, and she further urged students to think about what the potential resources might be in gathering evidence.

A couple weeks later, students shifted their attention to figure out how some modern plants and animals look like organisms from the Jurassic Period. Therefore, students engaged with multiple texts, media, and field work to ask questions and develop claims about which animals and plants resemble each other. In doing so, they further discussed how they can use their local community-based knowledge as evidence to build classroom science knowledge:

Ms. Spark: *Today, we're going to do some outdoor field work. We're going to go outside and we're going to look for some of the plants and animals that are around us and see if there's any that are similar to what we've seen in the video. First, we talked about the Allosaurus right here. Then, we talked about the Stegosaurus. He's got the spikes on the back or the plates on the back and the spikes on the tail. And then there's a little Juramia, or little elastic creature of the early eutherian mammal. Then we talked about the plants. So here is a fern. And there's a fossil of the fern would have looked like. So, in order for us to figure out, how eutherian animals like the squirrel or ferns like we see today, how did they survive, we're going to compare them to things that we see outside…*

Students go outside and conduct their field work (see Figure 19):

Figure 19. Students' Wonder Walk and Field Notes

Ms. Spark: *What can you say that we figured out about modern plants and animals compared to plants and animals from long ago? What can we figure out from the evidence we observed, or maybe some experiences you have around you about plants and animals?*
Ben: *There are animals that are similar to the Juramia, like squirrels.*
Amirah: *I saw a squirrel!*
Ms. Spark: *What are similar structures they have compared to the little Juramia from the video?*
Amirah: *They have sharp claws.*
Ben: *Tiny legs.*
Sarah: *Bushy tail*
Ms. Spark: *Okay, so there are animals that are similar to the Juramia like the squirrel. And it has similar structures to the Juramia. What else can we figure out?*
Violet: *Pine tree. The pine tree looked a lot similar.*
Ms. Spark: *Okay, so a modern-day pine tree looks very similar to the trees that we've seen that from the millions of years ago from the video.*
Easton: *With the pine tree years ago. The pine tree that we have, the bottom stick. Then it gets thinner and thinner.*
Ms. Spark: *So, those are some ways that they're similar that we can have trees that are really have long trunk, but then at the top they get smaller at the top. So, the video was also talking about the Allosaurus and the Stegosaurus. What did you say about that?*
Lincoln: *So, the video said there was an elephant before, and those are as they are, pretty big. They would be big like a Stegosaurus or maybe an Allosaurus. I have also seen an elephant and I was thinking how big it is.*
Avery: *They also had a long neck like a giraffe, I saw.*
Ms. Spark: *Okay. So, Avery has seen a giraffe before, and Lincoln has seen an elephant. Maybe that's how you can figure out how big these animals were.*
Avery: *When we go to the zoo, we always have to go to the giraffes because they're my mom's favorite.*

> ***Ms. Spark:*** *All right. So, you're going to write, a claim about can we find modern plants and animals. And we're going to use our evidence. Our evidence could be what we saw outside today. Our evidence could be what you've seen before, like the experienced you has like looking at elephants. And Avery seen giraffes before. So that's some of their own personal experiences, and that's their evidence that they might add to their claims. So can we find modern plants and animals that look like organisms from long ago. You need to make sure that you add your evidence.*

During this experience, Ms. Spark started off by going back to previous lessons and summarizing what students have discussed and figured out about different types of prehistoric organisms. After introducing the DQ and setting the goal of the local field work, students took a wonder walk in their school yard to closely look for organisms that might be similar to those prehistoric ones using their evidence-based chart. Most importantly, different from the previous years, Ms. Spark explicitly changed her narrative of what evidence to collect and what might count as evidence to support claims. In doing so, she encouraged students to use their previous everyday experiences and family stories to take as a form of evidence to relate to the phenomena and generate explanations. Her dedication to promoting the use of evidence grew over the years and paid off as students became aware of and continually discussed the importance, rationale, and various forms of using evidence in the process of making sense of science phenomena.

Snapshot #6: Connecting students' resources and cultivating consciousness

In the 2018-2019 school year, Ms. Spark starts engaging with the critical questions of how and why to support students' SEL experiences, and how to promote equity-oriented instruction by mainly following the guidelines from the curriculum material. Working with SEL and equity learning goals was a new experience for Ms. Spark when teaching science. During this period, she started to figure out ways to promote students' science interests and bring their family and community-based knowledge and experiences to science. Nevertheless, there were missed opportunities in terms of meeting the SEL and equity goals, and facilitating critical conversations among students where students can start identifying and raising questions to engage with critical and cultural phenomena.

In the beginning of the Toy Unit, students built their prototype toys and investigated figuring out how the motion (speed and direction) of their toy can change. In this particular lesson, the specific SEL goal was supporting students in developing interest towards science. In doing so, Ms. Spark's goal was to help them identify what they are interested in and how they

can build, refine, and change their toy designs or prototypes (based on these growing interests) over time. To support that goal, she introduced a short video of a boy from Uganda:

> ***Ms. Spark:*** *Last time that we were together, our big question was how can we describe the motion of toys that we build? So, we are trying to move towards the answer to how can we design fun, moving toys that kids can build. We watched this little video of the Uganda boy, remember that? He used some materials that he just had around him. We said those are kind of like maybe some recycling materials or things that were just laying around that he could easily build a toy. What did he make?*
> ***Jenna:*** *A toy car?*
> ***Ms. Spark:*** *And how did he feel when he got all done making the car?*
> ***Carter:*** *Maybe proud of himself.*
> ***Ms. Spark:*** *Yeah. He felt pretty proud of himself that he was able to make a car that actually could move. So, we're going to today we're going to make a prototype of a toy with some materials that you might just find lying around. What's a prototype? I think we talked about this last time.*

This part of the lesson connected to equity and SEL goals of the curriculum material. The learning goal also guided students to develop science interests and identities as they start relating with phenomena and build and refine artifacts aligned with these changing interests. By introducing another a child from Uganda, Ms. Spark aimed to support students in thinking how other children from different parts of the world also shared the same interest and joy in building toys and figuring out different ways to make fun moving toys. Even though this equity and SEL integration started a conversation on how to relate and connect with other kids, it remained superficial in terms of discussing how kids can build those interests, what makes them interested in building toys, and what different contexts and resources they might have in engaging with such interest.

Besides, Ms. Spark was quite enthusiastic and vocal about bringing her life experiences and family connections to the phenomena, which allowed students to know more about their teacher, and encouraged them to start building more meaningful relationships with Ms. Spark. The following example from one of Bird Unit lessons represents such experience:

> ***Ms. Spark:*** *All right, so when I walked around and listened to some of your responses about the hawk eggs. I heard some people say that they might look the same, because they look a little bit like their brother or sister. I heard some people say they might look alike because they're the same species. I also heard some people say that they might look different because they do not look like their brother or sister. So, some of you talked about your siblings and how you might look similar or different than them. I thought I'd share the pictures of me and my sister.*
> ***Sally:*** *You do not look like her!*

Ms. Spark: *You don't think we look alike? I mean, what are some ways that we're alike?*
Leo: *Your smiles are different.*
Mason: *Your hair is the same.*
Lucas: *You have same facial expressions.*
Nina: *Same eyes.*
Payton: *Your hair is a little bit shorter.*
Ms. Spark: *Okay. What are ways that we're different?*
Chloe*: A lot of ways. She doesn't wear glasses.*
Mason: *Her bangs are straighter.*
Nina: *She has bushy eyebrows.*
Ms. Spark: *Okay, what you don't know is the way we act. Some of our mannerisms, the way we behave. For example, I like to talk with my hands. She does too. So, some of those things are the same, but we act a lot completely different.*

Hearing more about their teacher's story encouraged students to bring their own family experiences related to phenomena in the rest of the lesson. From that perspective, Ms. Spark had a mindful first year in getting to know her students and their families and the ways of bringing these connections to the science classroom to provide more relevant learning experiences.

The following **year of 2021-2022** represents visible growth in terms of how Ms. Spark prioritized even more how to connect family and community knowledge and connections while experiencing, discussing, and making sense of phenomena. She made an ongoing effort from the beginning to the end of the year to know her students, who their families were and their place in their small community, and what experiences and connections they could bring to science. The evidence of her effort is her invitation for parents to join and facilitate one of the lessons in the Bird Unit. She explicitly declared that parents are the critical experts and stakeholders of the science learning community.

The following excerpt represents various moments from two consecutive lessons of the Bird Unit. The excerpt provides exchanges from students' outdoor experience where they have a wonder walk and sit spot as they observe the local birds in their school backyard to figure out how the birds near their school have similar and different traits, and how these traits could be the indicator of different stages of the bird's life cycle (chicks, juveniles, or adults).
Before starting the outdoor investigation, Ms. Spark introduced students with the DQ: Are the birds near our school chicks, juveniles, or adults? Following, students took their binoculars and science notebooks outside to make their observations, draw and/or write what they observed. They took a walk to spot diverse type of birds and then they sit in their sit spots to carefully listen to the sounds and discuss the features of birds around them:

Ms. Spark: *What kind of bird do you think it might be?*
Noah: *It might be a black crow.*
Ms. Spark*: How do you know that?*
Ms. Spark: *Do you think it's a chick, adult, or juvenile?*
Sarah: *I think it's an adult.*
Ms. Spark: *How do you know it's an adult?*
Ben*: They are so big.*
Ms. Spark: *Are there other ways to know its adult? Let's talk about what evidence we gathered here if we see the signs of chicks, juveniles, and adults. What do you think the difference between juvenile and adults?*
Jess: *Their feathers, and maybe how it flies. We also saw chickadees over there!*
Ms. Spark: *Okay, what are they doing?*
Gabriel: *Trying to protect their nest, so maybe she has some chicks maybe some eggs and nest.*
Ciara: *Going around the trees, they were crawling back and forth and chirping.*

Following this brief discussion, Ms. Spark asked students to gather in their own small group and gave them sticky notes to write their one question for DQB about the different stages. Ms. Spark collected and read them aloud: are chicks hatching in early spring or late spring, does the juvenile have different feathers than the adult? how do you tell if it's a female, and does it juvenile have different color patterns than the adult. After reading students' questions, she raised a question to make students think about the criticality of evidence to address these questions. She also encouraged them to think what the different ways are of gathering evidence and constructing knowledge which aligns with her consistent focus on evidence over years:

Ms. Spark: *How can we gather evidence to figure out some of these questions? What can we do to try to figure them out?*

Sarah: *We can go outside and look out the birds and we can look for adult, baby and juvenile and see the differences in their feathers and color.*
Miley: *We can look at the birds that we see today on our website (she refers to the Cornell Lab of Ornithology that they use during the unit)*
Ms. Spark: *Okay, let's go back inside now and next time, we're gonna one more digging to find some evidence to answer these questions, and it's gonna be fun!"*

A couple days after this outdoor investigation, Ms. Spark invited one of the student's parents, Ted who is interested in falconry and his friend, Nina who helps out, to speak to the class. He introduced falconry and showed different local birds to students. During this lesson, Ted and Nina had an interactive discussion and shared insights about the features and life cycles of Red-Tailed and Harris's hawks which connects and builds on the previous lessons (see Figure 20):

Ted: *Hi, I'm Ted, the dad of Avery, I'm a falconer at the State of Michigan. I'm here today to showcase a couple birds for you. This is Nina and her husband is actually my sponsor. Today, we're going to go through some questions and answers and share some cool stuff about birds as falconers. Ms. Spark, I'm going to attempt to tight into your lesson while I get into the habitat by talking about features and birds, and what else?*
Ms. Spark: *Features of the birds would be great! We talked earlier in the year about the traits, web of food, the stages of them and then what things are on the predators and prey.*
Ted: *So, I guess the first thing we'll touch base on is their habitats. What kind of habitats do they (the hawks) have and need?*
Emma: *They would be in like woods.*
Jake: *They would be in trees.*
Ciara: *My grandpa's house! I saw a hawk go down and it was hunting mice.*
Ted: *Awesome, so let's talk about birds of prey in particular. We have a red-tail hawk with us. This is Zazu (see Figure 21). About 90% of their diet actually is mice in the wild they will occasionally take rabbits and squirrels. Their digestive system is so strong. They can digest and dissolve the bone and everything. Zazu is a one-year-old red tail hawk. Can anybody tell me* ***how I know*** *this is a 1-year-old bird? Any ideas?*

Figure 20. Ted and Nina's Visit

Ben: *I think because you specialized in hawks, and you know the feature of what 1 year old hawk.*
Ted: *Great answer! (Joyful laughs in the room) What do you think?*
Jason: *I think because of the feathers.*
Ted: *Which feathers in particular?*
Anara: *The tail?*
Ted: *Yeah. Does anyone see the tail feather here?*
All student: *Yes!*
Ted: *See how its tail feathers are brown and black? Every newborn red tail hawk in the wild, they'll have brown and black tail feathers like that. At a year old, during the springtime, they are going to start going through what they call a moult. When a bird moults, it means they lose all their feathers from last year and they grew new feathers in for this season. The first year of the moult, they lose these brown and black barred feathers and then their new red-tail or orange color tail grows in.*
Nina: *Okay so this other bird has a little introduction. This is not a bird that you guys would've seen around here. This bird is not native to Michigan. This is called a Harris's Hawk. This is a desert dwelling bird. Habitat wise, like I said they lived in in the desert*

you can see them in Arizona, New Mexico, Western Texas. You can see them in southern states. When you talk about habitats with what would you expect of a bird out of a desert? What do you think they might be hunting?
Jordan: *Maybe rodents?*
Nina: *Yes, they do feed on rodents. What else do you think they might be feed on?*
Will: *They might feed on like lizards that can live on the deserts.*
Jake: *Snakes or rabbits?*
Nina: *Sure, there's something that's really prevalent in the deserts. what kind of particular rabbit?*
Jake: *Desert rabbit!*
Nina: *You're right! (Laughs in the room) There's also something that's very unique about that type of hawk. It's the only social bird of prey. What do we mean by that? She has a cast mate which means another bird just like her that she flies and hunts with. They're the only social bird of prey so when they hunt, they hunt like a pack. Kind of like wolves. People actually call them wolves of the sky because of that.*

In between and after these exchanges, Ted and Nina also informed students about the specifics (reasons to start, certification process, obligations etc.) and their experiences on practicing falconry. Ms. Spark and her students also showed interest to learn more about the similarities and differences between the traits, nutrition, and life stages of the Red-tailed, Harris's hawk and American Kestrel. At the end, students and Ms. Spark showed their appreciation for the visit. Ted and Nina promised to visit again, with the plan of taking the birds outside to the school yard to observe their behaviors.

This event illustrates how dedication and investment to connect with and build relationships with multiple stakeholders, like parents, pays off for teachers to promote critical, meaningful, fun, and relatable science learning experiences for students. This experience also encouraged students to affirm that their families are also a valuable part of their science learning and how they are welcomed to bring their cultural connections and experiences to science phenomena.

If Ms. Spark did not care to build relationships with her students and their families, we wouldn't see how students in school learning experiences can be supported by the involvement of community stakeholders. Through Ted and Nina's thoughtful facilitation, students show interest and ask a lot of questions about the habitats, nutrition, migration patterns, and life cycles of birds. Ted and Nina also nicely connect back to what Ms. Spark and students previously worked on which is figuring out the ways of identifying the age/life stages of the bird. Through the example of Zazu, students had further conversations of identifying the bird's life stage.

In the **final year of implementation (2022-2023),** the integration of students' cultural resources (within students' family and community-based experiences and knowledge) to phenomena peaked. Ms. Spark included a number of critical read aloud experiences for students and supported them to conduct family and peer interviews regarding the phenomena. As students highlighted their cultural resources they also started to relate more to other scientists' stories and feel more interested and confident about being a part of a science community. Throughout the year, Ms. Spark also frequently reflected on her critical awareness and consciousness on equity and justice connected to phenomena. She prioritized asking critical questions and facilitating discussions about critical phenomena where students identified and critiqued social, cultural, and environmental inequities taking place in science and society. Acknowledging that facilitating these critical discourses, also a new experience for her, she showed investment to foster her own and students' critical consciousness when teaching science now and the future. To contextualize how these changes occurred and look like in the classroom, I provide three brief excerpts from each Unit.

In the middle of the Squirrel Unit, students engaged with the question o**f** are there a lot more trees in some communities than in others, aligning with the equity goal of the lesson. Using the lens of social justice, they worked towards explaining how some communities have more trees than others, what are the impacts of this inequity, what might be the underlying reasons for that, and what critical action they can take to design solutions.

To do so, Ms. Spark and students initially brainstormed about the DQ. Then, Ms. Spark introduced a number of aerial pictures of different communities from different states and locations. In that way, students predicted and compared the number of trees in these communities and discussed if there would be more squirrels (and biodiversity) in some of these areas than others:

> ***Ms. Spark:*** *All right, first of all, we're trying to figure out why we see so many squirrels, but we can't find any Stegosaurus. We have been studying really close at squirrels, and we figured out that they get what they need. We are able to see lots of squirrels because they get, they get their needs met. So, our question today, are there a lot more trees in some communities than others. What do you think about that question?*
> ***Miles:*** *Yeah, because, in some communities, there are small towns that are like that. Then there are also big cities like New York and Boston.*
> ***Jordan:*** *I think yes because they're just like little prairies.*
> ***Maya:*** *Yes, because there is a lot of deserts in the world, and most of them don't have any trees.*

Ms. Spark: *Okay, so it depends on where you're at in the in the world. What do you think, Thomas?*
Thomas: *Yes, we walk by some places like around, let's say my grandpa's house. There is one, two trees and that will be our apple tree. And I saw a tree that was just born there surrounded by bricks. But there is also let's see like in New York, that might not have a lot of trees.*
Ms. Spark: *Okay, thinking about the trees that you said that the squirrels need in order to survive, let's look at some cities and let's look to see if we notice, the trees in the different cities. Turn your eyes now you can look at the screen. These are some aerial views of Chicago. This one right here is Woodlawn, a community in Chicago. And then this is another one called Hyde Park. What do you notice about those two?*
Jabbar: *Woodland Chicago is lighter, and the Hyde Park is darker.*
Ms. Spark: *What do you think that means?*
Jabbar: *That means Woodland has large trees and Hyde Park has even more trees.*
Helen: *I noticed that inside Woodland, they sprinkled in the back yards. In that part of Chicago, it looks like that there's just a couple trees sprinkled in every back yard and in Hyde Park It looks like there's more trees. There's one huge forest.*
Ms. Spark: *What we were talking about how squirrels need trees to survive. What do you think about the squirrels living in these communities?*
Jeremy: *I think in Hyde Park, there's more squirrels because there's more trees.*
Betty*: Because squirrels live in trees, and they give them food and to survive.*
Ms. Spark: *Okay, why do you think there's more trees in one part of the city than the other part of the city?*
Carrie: *Maybe I think, because there are more people living in one place, they need to build more houses. So, they, take down more trees.*
Amirah: *In one spot they don't get enough rain, like some, they get more sun and one part.*
Following, Ms. Spark introduced the news article that they are going to read and reflect critically on:
Ms. Spark: *All right. So, we're going to read this article. It's called Trees Grow on Money. What do you think it's going to be about? Jose?*
Jose: *I think it's about the trees and the cities. The cities have like more cool stuff than in the country. I think that's what it's about. In the cities, there is more like amusement parks or theaters, even like more trees than there is not in the country.*
Brandon: *I think it says money. Maybe it talks about how the trees make the money to build the cities. Like, not like natural resources. Become human resources.*
Ms. Spark: *All right let's read. It says researchers find that richer areas in the US cities have more trees.*
Kason: *What does richer areas mean?*
Ms. Spark*: What does that mean? What do you think richer areas mean?*
Nelly: *I think it means there's a lot more like, going on, and there's more money.*
Ms. Spark*: All right. Maybe it's a place that has more money. What do you notice about this picture that tree lined city street?*
Sam: *It has lots of cars, alongside the road and there's lots of trees.*
Ms. Spark*: Even though there's lots of cars, it looks like wealthy areas has lots of trees in there. Why do you think that people want to move where there's trees?*

Sean: *All the trees are going to make cold air because if you're in the shade.*
Amirah*: There would be more animals there, like squirrels. So, there would be more compost for trees.*
Jose: *They would want to move there because it gives them refresh air and shade.*
Lincoln: *When I am sad, I sit by a tree, I always go get my book, and I just sit down by a tree.*
Ms. Spark*: All right, Schwartz's (the author) study is a call for cities to think about equity when developing tree planting goals. What does that mean to think about equity? What word do you kind of hear in that word?*
Sally: *Community?*
Ms. Spark*: Sure, sounds a little bit like that.*
Jabbar: *So, what is it equal to?*
Ms. Spark*: What do they want to be equal?*
Nina: *Um. Trees. Planting goals.*
Ms. Spark*: Okay. trees. Planting trees. Equal for whom? Who do they want it to be equal amongst?*
Thomas: *Equal trees in each city. I think it means like, equal trees for wealthier areas and poorer areas.*
Amirah: *Planting trees to those poorer areas. So, they can have more fresh air.*
Avery: *They should make more trees. The poorer areas should have more trees because they need fresh air like everyone else.*

In her implementation for years, this was the first time that Ms. Spark explicitly ask students what equity might mean. This particular lesson becomes a starter point for Ms. Spark to use the lens of social justice to raise critical consciousness about the phenomena. She asked critical questions to support students in explaining how some communities have more trees than others, what might be the impacts and reasons of such inequity, and what critical action they can take to address these environmental injustices. Through these questions, students brainstormed the notion of equity for the first time. They critically reflected on how equitable planting goals is needed for underserved areas and communities.

After reading and discussing the article, students work together to write a community letter draft to send a representative asking the city to plant more trees and start equitable tree-planting program to disrupt environmental injustices and respond the needs of underserved areas and communities. These are first-time experiences for these students to identify and critique the existing inequities. Realizing more the importance of having these discussions, Ms. Spark work towards more on amplifying and taking more visible steps to guide students in developing critical consciousness rest of the year.

In the beginning of the Toy Unit, MS. Spark and students shift their attention to reading a book about Lonnie Johnson, the engineer who designed the Super Soaker, to make connections and define solutions to their own toy design problems. As they relate to and reflect on some of the early life and science experiences that Lonnie Johnson had, students start thinking that they can also use science, engineering, and technology to collect and strengthen their voices, and use science to promote equity, aligning with the SEL goal of the lesson:

Figure 21. Moments from the Read-Aloud of the "Whoosh!"

Ms. Spark: *All right. Today, we're going to read a book about Lonnie Johnson, so we can figure out more about how he came up with his ideas. Lonnie Johnson designed the Super Soaker. While you're listening to this, I want you to think first of all, what kind of person is Lonnie? And second what can we learn about his designs, as we're designing and engineering our own toys. These are things that he designed. There's a Super Soaker (see Figure 21).*
Ms. Spark: *Every day brought a challenge for young Lonnie Johnson. The challenge of finding space for his stuff. Six Johnson kids were squeezed into their parents' small house in mobile, Alabama. Lonnie would have loved a workshop of his own, but there just wasn't any room. There was nowhere to keep his rocket kits. Bamboo shooters, rubber band guns, go cart engines, bolts, screws, and other parts. His dad let him bring him from the shed and various other things that he'd hauled back from the junkyard. Loni loved building and creating ideas for inventions just kept on flowing. How many of you like to collect junk stuff? What do you do with your stuff?*
Chris*: I make little action figures.*
Sarah: *I like to make dresses for my Barbie dolls.*
Ms. Spark: *You like to do things with your Barbie dolls and make different inventions with them. So already, what kind of kid do you think that Lonnie Johnson is?*
Jose: *Creative.*
Amirah: *He has good ideas.*
Sam: *He's a thinker.*
Ms. Spark*: All right. He learned how to make rockets from scratch… Kids at school gathered to watch Lonnie launch them, and he learned how to make rocket fuel when it caught on fire in the kitchen. Lonnie's mom didn't make him stop. She just sent him outside to do the work. There he is launching his rocket for his friends. Lonnie wanted to spend his life designing things, building things, getting them to work. He wanted to be an*

engineer. However, Lonnie took an exam that said that he would not make a very good one. His dream had been challenged. Lonnie was discouraged. What do you think about him taking the test and then telling him that he wouldn't be a good engineer? What do you think about that?
Kyle: *They're being rude.*
Mason: *They're not really encouraging him to do better.*
Ms. Spark*: So, do you think he's going to give up?*
Students: *No, no!*
Ms. Spark: *Okay. His school's team took freshly finished Linux to the 1968 science fair at the University of Alabama, where only five years earlier, African American students weren't even allowed to enter. How do you feel about that?*
Students: *That's mad!*
Students: *Yeah! That's sad.*
Sam: *Not fair!*
Ms. Spark: *But that didn't stop him having to compete in a place that still wasn't very welcoming. Well, that was a challenge with a capital C against other schools from all over the state. Lonnie's team won first place.*
Students: *That's good!*
Ms. Spark: *So, he had a challenge when he went here because not very many African American people were entering in the science fair. What other challenges, as he had in his life? What other challenges as he had in his life? Think back to his life from the very beginning till now.*
Amirah: *One thing giving commands to the robot.*
Ms. Spark: *Right? Like trying to get Linux to work. That was a challenge. It took them years to do that.*
Mason*: A lot, a lot of challenges. he's getting better as he goes.*
Ms. Spark*: He's getting better as he goes…Soon Lonnie left home to go to college at Tuskegee Institute, where he stood out as a self-confident, insightful, creative thinker. He stood out as a student who asked the right questions, precisely defined problems, and he formulated solutions to problems. He became an engineer after graduation, and that took him beyond Alabama, way beyond. Did people expect that he could be an engineer? Remember at the very beginning? What do we know about Lonnie now after he's gone through some more in his life?*
Sam: *He creates stuff like he created the Super Soaker.*
Emmett: *That he never gives up, even though it doesn't work. Like he never gave up on his robot thing.*
Ms. Spark*: This would make a great water gun. First, he had to find or make the parts, including the pump, because they had to be small enough for a child to use. Right? Then he had to glue the parts together into a prototype. Does that sound familiar? Where have you heard of that before? Prototype?*
Jose: *Maybe the skimmers and carts we did.*
Ms. Spark: *Yeah, Jose thinks those would be, prototypes that maybe we could improve… So finally, Lonnie decided he was going to test his strange looking squirt gun at a picnic. A boy asked. Sure, Lonnie said. Want to see? Lonnie worked the pump with a squeeze, which squeezed air into the chamber, and when he pulled the trigger, the air escaped, forcing water out with.*

Payton: *So, everybody can know how it works!*
Jabbar: *It's kind of like a sprinkle.*
Ms. Spark*: What other people will be really super interested in a squirt gun?*
Students: *Kids.*
Chris: *Kids! He went to the park. I know why he used the Super Soaker for watering plants.*
Ms. Spark*: Well, how could we use what he did as an engineer to help us to do some things in here with our toys? What do you think we could do?*
Sean: *Make our toys better.*
Ms. Spark*: So, maybe redo some redesigns.*
Emmett: *Never to give up.*
Ms. Spark*: Never to give up. Definitely. Even though it might fail, we'll probably have failures… but keep pushing to make it work!*
Sarah: *Add stuff to it.*
Ms. Spark: *Add some things to our toys. Maybe make them better. He just had confidence in himself. He just kept saying he could do it. How did he know that they were a good invention? How do you know that was going to be something that, like other people would want to even use or to have?*
Lily: *Watch and see if other people had fun with it and liked it.*
Kyle: *He tested it, and if he didn't work, he added things.*
Ms. Spark: *So, he tested it, and then if it didn't work, then he changed or added some things, and then he tested it some more to see what it would do. Brimley.*
Ms. Spark*: Yes, what are we going to do with our toys? To see if other kids would be interested in them and want to use them or build them? What our plan was that we kind of our last lesson that we were doing?*
Amirah: *We put together like our toys. We're going to ask 1st graders. And ask further if we should add stuff.*
Ms. Spark*: Yeah. We're going to do interviews. We're going to show them what it does, how it moves and we're going to ask them some questions, have them play around with it, see what they think, and then maybe we'll be able to make some changes from there.*
Sam: *Like make it go like a little faster.*
Ms. Spark: *Exactly, if we show the first graders like Lonnie did, and they're like, yeah, it doesn't go fast enough, we want to add something to it.*

This exchange illustrates several important inferences. First, Ms. Spark foregrounded Lonnie Johnson's story to help students to relate with him in terms of being a young kid who experiences the feelings of wonderment, joy, confidence, and resilience in building toys and being a part of a science community like them. Students saw Lonnie Johnson as a creative and smart inventor and scientist that they could use as a role model as they also developed interest in science, design and redesign solutions for their toys working with and getting insights from younger kids.

Second, as they read Lonnie Johnson story, students had a chance to critically think and reflect on a) his resilience as a scientists who never gives up, keep working and keep testing his designs until he solve the problems, b) how he had never ending curiosity to solve problems and worked at NASA as a successful scientist, and c) how he had to go through various challenges, such as following his ambitious science and engineering goals, as well as keep resisting historical and political climate and tensions of the US while studying at University as an African American student. With these critical aspects, this lesson evidently brings many sensemaking elements together, as students work towards sustaining their science interests (SEL) and literacy skills by engaging with critical read aloud. They also continued to develop having critical discourses about the science and engineering processes, successes, and challenges of scientists of color experience.

Finally, in the beginning of the Bird Unit, students engaged with the DQ of what we know about birds from our families. To address the question, they conducted interviews with their family members (parents, grandparents, or siblings) following the brief interview protocol they have. The equity goal of the lesson focused on making students' community and cultural resources, and funds of knowledge visible in the process of knowledge construction and sensemaking. By this lesson, students figured out that their family and classroom experiences with birds from around the world all add to the knowledge they built together in the classroom:

> ***Ms. Spark:*** *Our big driving question is we want to help birds around our school grow up and thrive. We've been doing some work to* ***trying to identify*** *some local birds around here to* ***figure out*** *what birds live here. You* ***did an interview****, because we want to know what we can learn about birds from our families. Who wants to be first to share their stories? Rosalia, you can start first. Your job is to listen and be ready to think about some questions that you might want to ask Rosalia. When she gets done sharing, we're going to discuss with our friends near us, maybe find like a question that we might want to ask the person that's sharing, so we can hear a little bit more about what their families know about birds.*

Figure 22. Rosalia and Mable's Family Interview Presentations

Rosalia: *My dad's favorite bird is a robin because it's beautiful and it's the state bird. My mom said, we love seeing birds hanging out by our deck, because we have bird feeders, and she likes to see all kinds of different birds enjoying the seeds. We have out there for them. I have pictures of some of the birds we see around our house (see Figure 22).*
Ms. Spark: *How nice, what are they?*
Rosalia: *That's a robin.*
Students: *That's cool!*
Ms. Spark: *What's your other picture you have?*
Rosalia: *That's the bird feeder at my house.*
Students: *Wow.*
Ms. Spark: *All right. Why don't you just turn and talk to your friends nearby and come up with a question you want to ask Rosalia.*
Jake: *Have you ever seen any birds on your roof?*
Rosalia*: On my roof? Yes, I have. For like, one second. Yes, Sean.*
Sean: *Which birds come to your bird feeder?*
Rosalia: *A lot of them. I don't count them, but robins for sure. Kate?*
Kate: *Have you ever gotten, like, really close to one of them?*
Rosalia: *I tried, but then Anika called me over, so I couldn't. Christa?*
Christa: *So, do you live next to Anika?*
Rosalia: *Yeah. We are like, neighbors real close. Jayden?*
Jayden*: What's your mom's favorite word, though?*
Rosalia: *She likes all of them. Chelsea?*
Chelsea: *What's your favorite word?*
Rosalia*: Cardinal. Emerson?*
Emerson*: What bird species do you have the most around your house?*
Rosalia*: I see cardinals every day, also Robins.*
Ms. Spark: *I was curious what you put in the feeder to get him to come to the feeder.*
Rosalia*: We had corn and like this other food that I don't know.*
Ms. Spark: *Okay, what's the other food? Is it like a seed or green that you put in, or is it something different?*
Rosalia*: I think it's like a green block.*
Ms. Spark*: Oh, it's like a block or something.*
Mable: *My grandma has that. She mushes all different bird food together. And she just puts in this little thing, like a cake.*

Seamus: *How many times do you feed your birds? Like, do you feed them every day?*
Rosalia: *When they run out of food my dad puts more food in there for them.*
Ms. Spark: *Okay. Who wants to be next? Go ahead, Rosalia, pick somebody.*
Rosalia*: Mable.*
Mable: *I interviewed with my grandma (see Figure 22). Her favorite bird is a cardinal, because she thinks, it's her spirit animal. So, this thing is all about Cardinal. She has a relationship with Cardinal. One time there was this cardinal just keep coming up to her door. There were two of them. There was the male and female and they just kept coming up to her window, and she kept getting close to them. But then they just went away. The one time they stayed there when she got close to them, she took a picture, and they were like cuddling. They were hugging.*
Ms. Spark: *That's so cool. What did she say? Her spirit animal?*
Mable: *Yes, she thinks of it. She told me that she collects a lot of Cardinal stuff because, she thinks that they are like her relatives from the heaven. That's what our family thinks of Cardinals. So that's really what we have.*
Ms. Spark: *Okay, come up a couple of questions.*
Kayla: *Do you have a favorite bird?*
Mable: *Probably my favorite bird is the Red Cardinals, because I just like the colors of it. Nina?*
Nina: *Do you believe the same story as your grandmother?*
Mable: *Yes.*
Seamus: *Why the cardinal?*
Mable: *I just feel like the cardinal is so pretty and like it's been in our family for generations and generations. So, I really like the cardinal. It's like a reminder of your history and generations that you had. So that's why I really like it. Miles?*
Miles: *How many cardinals were there?*
Mable: *There were two cardinals. There was a girl Cardinal which is more of a brownish and then there was the boy cardinal. That's a really pretty red. Natalie?*
Natalie: *How did your grandma get so close to the cardinals?*
Mable: *Well, so there's this window there. And she normally puts some food for squirrels onto the window., the thing on the bottom. So, all they do is they sit there, and they eat out of it, and then they're preoccupied with food, so they don't go anywhere when people get close to them.*
Ms. Spark: *All right, so our big question was what we can learn about birds from our families. After listening to our different interviews, what can you say that we've figured out about birds from different families?*
Nina: *Their favorite birds, like cardinals.*
Jason*: About robins and bird feeders.*
From Students to Ms. Spark: *What's your favorite bird?*
Ms. Spark*: I really like the Eagle. I know that a lot of people like the Eagles, but I think that they're really just majestic. The way they fly and the way they capture their food, I think is really neat… Some of you probably know that my son passed away in 2008. So, we've seen an eagle flying over our farm, the day of his funeral. So, when I see eagles, I always think of Trent. So that's one reason why it's my favorite.*
Jayden*: Do you have any interesting stories to share about a bird?*

Ms. Spark: *Let's see. There was one time, there was this Robin, and every morning it would come to the window, and it kept pecking at the window. I tried to go to the window to, like, scare it away, and it would just keep pecking at it and then it would go away during the day. But every morning it kept going to the window. No matter what we did, it would not go away. Anyway, as we listen today, some families or cultures has special relationship to certain kinds of birds. I would say the cardinal story that you guys shared about how it's a loved one, that was always something that my grandma always said too. She says, if you see a cardinal, it's somebody from heaven looking over you.*
Amirah*: So, your son Trent is looking over you.*
Ms. Spark: *Yeah, I'm sure he probably is looking over. You guys have any other questions for me?*
Rosalia: *My grandma and grandpa, they have a bird that that keeps pecking at the window. Why do you think they do that?*
Ms. Spark: *People always told me it's because they see their own reflection. I'm not sure if this is true, but it might be. They see the reflection and they think it's like another bird or it's like the dominance thing. It's almost like they were fighting with each other and really just fighting with himself.*
Jake*: Do you have bird feeders at your house?*
Ms. Spark: *Well, here's a funny story. During the Covid, you know, when we were at home a lot, I always thought, well, you stuck at home, so it would be kind of cool to watch the birds. So, I got a bunch of feeders, and I went down, and I got a bunch of corn that we raised on the farm, and I put some in the feeder, and I bought some other seeds. And we did have a lot of different birds come cardinals, blue jays, uh, chickadees. There was this junco bird. I didn't really know what it was, but I had to look it up. But they were really cool. But then I kept got to a point where I kept forgetting to put seeds in the feeder. So, then they just left, and I haven't picked that back up again to do it. So, feeders are still hanging there. No feed in them so birds don't come back anymore.*
Ms. Spark: *All right, so we have shared a lot of different family stories. We've learned about a lot of different birds. Like I learned about the bird of Paradise, which I never even have heard of that. So that's kind of cool. Maybe you learned some things from other people about the birds. Each student in the class has a different history, different experiences, different things that they know. Some things are similar to what you maybe are experiences you've had. So, you're going to just do a quick write about them before we leave…*

Rosalia, Mabel and Ms. Spark's insightful stories about birds were the highlight of this critical lesson. Students become the main actors facilitating the discussion and storytellers of the lesson as they shared their family knowledge, beliefs, and experiences about local birds. This lesson provides insights on how families' historical (generational) and cultural resources (such as stories) about science phenomena could serve as an instrumental way to bridge different ways to build and make sense of knowledge. As students shared and heard family stories, they figured out how different birds can carry different and special meanings for other families and cultures. Students also made sure to ask several interview questions to Ms. Spark to invite her to be part of

the sharing process. Ms. Spark openly and honestly shared her own family and personal roots and special connection to a certain bird, the Eagle. Similar to Ms. Spark, Mable's story about her grandma and other family members cultivated awareness on how and why different families build a special emotional bond and meaning with local birds, like the Cardinal.

Findings for RQ3

The findings of the RQ3 address the developing identity trajectory of Ms. Spark considering the three components of identity development based on the proposed framework. Since I already present findings on one of the core components of identity development through the changing patterns in Ms. Spark's implementation of practices, following, I provide insights on Ms. Spark's individual and collective level of experiences to bring further remarks on the remaining components. To do so, the I provide evidence from semi-structured interviews below to unpack: a) Ms. Spark' personal history and positionality, and b) her previous and current conceptions of ideal science learning and teaching environment considering the relationships she builds within her teaching community.

Ms. Spark's personal background and positioning: Who is Ms. Spark and what intersected social markers she identifies with as an individual?

I conducted a series of formal interviews and had number of informal conversations with Ms. Spark over the years. All these exchanges allowed me to get to know more about who she is, how she identifies herself, and what personal and educational experiences she had through the timeline of her life.

Ms. Spark was born in and grew up in Dansville, in a small rural community, in Michigan. After graduated from high school, she attended MSU since she was planning to be a veterinarian, because she loves animals. She soon realized that she was not feeling prepared for college. She felt that MSU was not the path she would like to take at the time, because she didn't have any family and connections at MSU back then. Years later, with the encouragement of her husband, she pursued her degree and graduated from a College in Olivet with honors.

Her first job was in the public schools of Olivet where she taught fifth and sixth grade. She recalls that time with the challenges she went through, because she was the only teacher, and she didn't have any support. Then, her dream job came open in another public school where she and her family lived. She still currently works in the same school after 25 years. In her first year,

she went through a traumatic, life changing experience when she lost his son due to an accident. The death of her son was a pivotal for Ms. Spark and made her ready for a change since she needed something different to keep her motivated in life. She started teaching third grade and teamed up and collaborated with another teacher. While she taught ELA, her colleague taught Math and Social Studies. She enjoyed teaching ELA for years. Around seven years ago, she shifted her focus to teaching science.

When I further asked how she would identify herself in her personal and professional life, Ms. Spark immediately talked about how farming and agriculture have a big space and impact on her early and current years. She mentioned her ongoing farming and trucking family business in addition to her teaching career:

> *I grew up in a farm. As a kid I, I always grew up learning how to use things, be hands on, like building things or creating things. So, that's the kind of person I am, more of a hands-on person. My husband and I grew up on a farm. So, we continued farming after I got married. We are still raising animals and crops… Doing that type of thing has been in my blood since I was young. It has always been satisfying to me because you figure out different ways of doing things and make things better and improve because each year is a new like cycle for farming. So, you learn new things and change as you grow.*

She continued to explain how who she is, her roots, and her deep passion for farming shaped the way of living her life and even her approach to teaching science. Her hands-on approach and community-oriented mindset in life informs her philosophy and conception of teaching science. She encourages students to connect their experiences from home to ones they had in the classroom while making sense of science:

> *I kind of took those things that I've learned as a kid through the agriculture, that rural background I have, and I bring into the classroom. I feel like that's something that I can do… I like to expose students to different experiences and connect them to the things they do at home with their families. The things that they've build or did at home which connects to what we were doing or connects to science. They know that I farm. So, they're really interested in that, and they like to have connections to that. I guess that has always been kind of my driving force to build that enthusiasm and build things that use your hands to learn skills.*

Ms. Spark continued to address that she is a passionate advocate of introducing what agriculture is and why it is really important for their community. In doing so, she works toward raising awareness on how students can relate to agriculture, and how and why agriculture and practices of farming could relate to the critical science phenomena (such as through erosion and pollution:

Growing up in agriculture really affected my science teaching because there's so many misunderstandings about farming. That's one of my passions is making sure kids understand that farmers are the stewards of the land. So, they're not going to mistreat the land and animals because that's their livelihood in this community. I know there are many kids and their families' backgrounds… I know which kids have a hobby farm, or their families are farmers. I can pull those kids into some of the conversations, and they really like that because they feel like they can relate and have similar experiences. So, they like to really connect with that…

For example, agriculture and nature related lessons probably easier for me and I can think of some of connections to make. Some science curriculums have those examples of erosion or the pollution where a lot of times it's blamed on farmers. They don't talk about how farmers go through a lot of state regulations, and how we have to follow a lot of rules about what we do. That wouldn't make sense because that's taking away from valuable aspects of why we would need to plant our crops on. I guess in any small opportunity I have, I just kind of plug that in there and get that in the back of their mind, so they know that there is a different aspect to it.

Ms. Spark explicitly uses her farming and agriculture experiences and knowledge as an opportunity to teach certain science phenomena by using a critical lens and encouraging students to identify and critique different aspects of the phenomena. Her insights support my argument on how who she is and what she identifies herself with impacts her decisions on what is important in teaching science. Her positionality informs what she prioritizes, such as getting to know her students and their families, cultivating awareness on how agriculture is a meaningful livelihood and as a way to contribute and being an active member of their community. Therefore, she introduces the scientific ideas and phenomena related to nature, plants, farming, and agriculture with ease and enthusiasm. Her multiple personal experiences (sub-identities) shape her interactions, negotiations, and her relationships with students and her ways of seeing and teaching science.

Ms. Spark's conceptions of ideal science learning and teaching environment: What values, knowledge, and belief systems she brings to her relationships with multiple community stakeholders

Earlier, I argued that conceptions inform and are informed by the personal background and positionality, as well as the contextual factors and collective-level experiences. Above, I briefly shared Ms. Spark's historical and social background, and her prior professional and personal life experiences from her own voice. Now, I shift my attention to address what

conceptions Ms. Spark has in relation to science teaching and learning by emphasizing the following points from Ms. Spark's own voice:

a) what values and beliefs she prioritize in relation to how an ideal science learning and teaching environment should look like,

b) what experiences and critical thoughts she has on the content of curriculum materials she enacted and,

c) what relationships she has with her colleagues, research partners, and administrators; and how these relationships inform her conceptions on teaching.

When I asked Ms. Spark about her core values and beliefs in teaching science, she shared what she prioritizes and cares about in her teaching. Her teaching conceptions include an inquiry-based teaching and learning environment where students can a) notice and wonder about and figure out the phenomena, b) have a meaningful and critical discourse with peers, and c) being empathy and care about other people's lives and learn more about their stories:

> *The inquiry, kids looking around, noticing, and wondering about things to me is super important. If they aren't wondering about the things around them, then they're never going to seek out any answers and solutions to the problems or try to figure out what's really going on. Then the discussion part is huge to me, being able to talk to each other, being an advocate for yourself and your ideas… I think that's also important working with other people, and you know, be empathetic, care about other people, just know that other people have a story, too.*

When she unpacks the components of her ideal teaching and learning space, she first explained how driving questions and discourse moves become pivotal to shifting her definition of good teaching, as well as becoming the way to supporting students in figuring out:

> *The driving question helps keep them focused, so they know what to expect and it gets them focused or geared up for what they're going to figure out in the lesson…It becomes more of them being able to figure out the phenomena to address to the question and it's not me just telling them. They take on that learning themselves and if they take ownership, they're trying to do things at home that are connected to what we're doing here. Until they actually have related to or applied it to something, they won't really realize why it's important or why they need to figure out… I also really like the discussions and just really pushing them to think deeper, and then the other kids agreeing or disagreeing, which helps them to explain or justify their claims using evidence. Sometimes I'll have to plant seeds or little ideas and that kind of helps them to start to get it to piece it together… I use tell me more or add to what they're thinking, or do you want to tell me in a different way? That got them to feel more confident in expressing their ideas out loud in front of everybody. That's good discourse move and teaching to me.*

Her remarks align with a) who she is as an ongoing learner who uses hands-on approach in life, and b) her teaching practice when she implements sensemaking practices. In line with the changing patterns in her teaching over time, Ms. Spark prioritized using DQs and discourse moves to moved away from a behavioral frame to a sensemaking frame as she sets the norms for promoting productive discourse, encouraged in the use of evidence to explain and make sense of the phenomena and connect home and school to provide more relevant science experiences for her students. This alignment or the match between how she portrays her conceptions of science teaching and how she actually teaches science supports my earlier argument on the reciprocal interaction and relationship between different components of identity.

Furthermore, as we discussed further about what Ms. Spark means by students being empathetic and being an advocate for their ideas, we embarked on an in depth-conversation on how she identifies the context of her classroom, school, and community:

> *Here, we're in a small community. There isn't a huge amount of diversity as far as like ethnicity or race, but there is a lot of diversity among our kids. I mean, some are living in really poor areas, and they don't have a lot. We've had kids who don't even have running water before, then, you'll have some kids who have a lot but of material things. They're going through other things in their lives, like divorced parents' kids or like kids have lost somebody important in their life and dealing with grief or a parent in jail. I mean, that's pretty common.*

Following, she addressed how the students' backgrounds and context shaped her approach/conception to what counts as equitable science teaching. She highlighted why and how she prioritized supporting students with diverse needs, such as students with special needs or students who struggle with writing and reading skills while engaging with science:

> *I've always been a person who's tried to be aware of other kids' situations and try to be empathetic to that. My life experiences probably have shaped how I look at kids. When I grew up, I have an older sister who's handicapped, and she was born with brain damage. She went through a lot of hardships in school because kids were not as accepting of kids with disabilities. I learned over time that every kid handles and figure out things differently, and every kid has some kind of story… For example, I've had kids either they're in Special Ed or maybe they're struggling readers or writers. I don't want those kids to feel less valuable, because they bring a lot of value to the discussion. In the end, if I spend a lot of time on the writing, I feel like I'm taking away from the part where they're really starting to discover, discuss and figure out about it…Even if they can't express themselves in writing, they can do it orally. I know I can get a grasp at whether they get the concept or not just by their performance in here and how they are collaborating with their peers…Being able to express themselves in a variety of ways is important to me.*

Her words reflect her concern of getting to know her students' various special learning needs to acknowledge them and then being responsive to them. To do so, she advocated for promoting equitable modes of participation through different ways of expressions and modeling in communicating and building knowledge in her classrooms. Her conceptions on how important it is to support students with diverse backgrounds and needs corresponds to her actual practices as she also connects students' cultural resources to science. Finally, Ms. Spark's remarks show her developing asset-based mindset toward her students as she centers students' strengths and values they bring into the discussion of science. One of the reasons for such a growing asset-based mindset connects back to her previous experiences with her sister with special needs as she became one of the support systems for her.

During my conversations with Ms. Spark, she also consistently commented on her experiences of enacting various elementary science curriculums over years. She reflected on to what extent these materials match her portrayal of an ideal science learning environment. Previous and current (ML-PBL) curriculum materials became one of the critical components to our discussions. Because Ms. Spark transparently reflected on how these curriculums shaped and kept shaping her conceptions and implementations of science teaching. Following, she shared her experiences and take aways on the previous curriculum materials she enacts:

> *When I was using the units that I had before, it was kind of hodgepodge, and I didn't really feel like I had a good flow of what students were going to figure out. I felt like I was just kind of stabbing in the dark, trying to understand. The focus was more on the writing part and not really the experience part of it…The kids were really not excited because it was more teacher-driven than it was student-driven. I was just talking to them instead of them working through the ideas. I was losing them because it was a lot of stuff was just thrown at them, and they were expected to do a lot. So, it wasn't differentiated for different levels of learners…Everything was like cookie cutter.*

Then, she expressed her thoughts on the current curriculum and how it aligns with her vision of science teaching and learning:

> *In the curriculum that I'm using now (ML-PBL), it is the way it needs to be. It needs to be more inquiry where students do have a product, or a project and they solve a problem in the end. You want them brainstorming and thinking through it. You want them to figure out as they go by using evidence. It's more me having to guide them through it, they're in charge of their learning process. So that is kind of a big difference… Students are anxious to figure things out and they know in the end, they're going to solve some problem. It's pertinent to them. It is life for them, not just here's some random science skills. It's more of like it's all connected to something that they wonder about and try to figure out why and they connect and apply to their life down the road.*

Based on her statements, the core differences between these curriculum materials are a) the role and agency of the teacher and student in facilitating the lessons (teacher-centered vs. student-centered), b) coherency among the lessons, c) encouraging students to figure out phenomena, and build artifacts to solve real world problems, d) responsiveness to students' multiple learning needs and d) providing a connection to students' everyday life and resources. I take these differences spotted by Ms. Spark and interpret them as a form of confirmation for her science teaching and learning conception and philosophy. Her insights about the curriculum materials also align with her preferences and choices in the implementation. I argue that curriculum becomes a living document that encompasses the contextual connection to Ms. Spark's conceptions. Whenever the curriculum aligns with her conceptions and positionality, it becomes more suiting, motivating, and easing for Ms. Spark to teach science. Therefore, it is complimentary to address teachers' take on the curriculum materials when trying to understand what constitutes their conceptions of ideal science teaching and learning.

As a final point of discussion, I unpack how MS. Spark talked about her relationships with her colleagues (teaching partner) and administration (school principal) from the school, and research partnership (through PL experiences with ML-PBL research team). Her relationship with these multiple stakeholders constitutes her experiences with larger institutional systems of teaching which critically impacts her way of positioning and teaching science.

When I asked Ms. Spark about how she started teaching ML-PBL, she immediately recalled her interaction with her curriculum coordinator and school principal. Her remarks show how important having these positive relationships within the larger administrative system is in supporting teacher learning. Ms. Spark needed to build her case by promising higher scores in the state level assessments, which is what the system demands, and had to negotiate for teaching science in a way that would align with her conception and vision:

> *I volunteered to the study (ML-PBL). My curriculum coordinator heard about it, and when she mentioned it me, I was very interested in doing it. The current program that we were working with, I was not completely satisfied with the results… I just went to my principal, and asked is it okay, if I do this. In order to sell it, I kind of said, well, I know the past instructor wasn't doing NWA with science in the third grade. So, how about I do that and then I'll show that they're growing because our scores were really low at the time when I came in here. It was the time in between Meap and M-step. He was all for it and he was excited about it. He thought it was neat that we were part of something that was ground up, innovative and something different.*

Following, she shares more about how she learns to teach ML-PBL that using new and innovative practices. In doing so, she refers back to the professional learning (PL) sessions that she attended in the first couple years of her teaching (during 2018-2020) before the pandemic:

> *The PL sessions were definitely helpful because you could talk to other teachers who are also doing the same thing and they're all at the same pretty much point on the lessons. So, I was asking them questions about what was working for them or what was not. That really helped and we did it periodically through. So, when I change the next unit, then I could, still talk to other people about where they were at…I've also appreciated what you guys have. I appreciate the program. That was a game changer for me because when I came, I wasn't sure if I really want to do this or if it is a real fit… It really helped me to grow and change and kind of evolve into this, I enjoy it.*

Her words signify how she enjoyed having the partnership with the ML-PBL research team and how this new curriculum that uses innovative practices supported her instruction in a more reform-based manner. She also highlighted how she needed the support from a community of fellow teachers who are also going through similar experiences and challenges in teaching new science curriculum and enacting new practices. That was the core part of the PL sessions for MS. Spark, since she starts feeling isolated and disconnected from her colleagues after the pandemic (when she stops attending to PL sessions):

> *I never made it to any PL after 2019, you know because after the pandemic things got complicated here especially with the subs. I don't want to sound like a person that thinks I know everything, because I know there's so much more that I need to know... I think I'm getting stagnant, and I don't really have anybody that I can have a conversation with. For example, my principal comes in. He's like, "Yeah, checks all the boxes and everything's great," but I don't really know. Am I on the right track? Am I doing what I need to be? One thing I lack there is that I don't have communication with any of my colleagues. It might be a two-minute conversation out the door, then I got to hurry up and tell somebody about something, or asking a question about a kid, or something… Lately, professional development days for me, is me by myself…*

About her relationships with the people from the systemic/institutional level, Ms. Spark commented on her positive, but superficial communication with her principal. She also addresses the level of her collaboration with Katie in teaching in an honest and vulnerable manner:

> *That is nice to have Katie, because we can debrief after a while. Like that didn't work, or whoa, did you see the excitement on their faces? and then we can just talk about what we could do to adjust. Say, "Well, I want you to target these kids, because I can see that they're not." And sometimes she'll do the models with them. That helps because then they can talk to her to try to figure out what's going on…So, she's supposed to be kind of like an interventionist, helping kids that are struggling learners. But since the pandemic, she's*

gotten less and less interested in working with kids. I see that's a hard thing because I know what I've had in the past… So, it's kind of feeling like I'm alone again.

All these remarks prove how critical it is for teachers to build positive relationships with multiple stakeholders and stay connected in the partnerships in various levels of curriculum, instruction, and research. Teaching is a complex act and a social and cultural experience that needs to be supported by these multiple layers of involvement and interactions within the community. I appreciate Ms. Spark's enthusiasm and ongoing endeavor to stay connected and work towards staying relevant with the developing aspects and critical conversations in teaching.

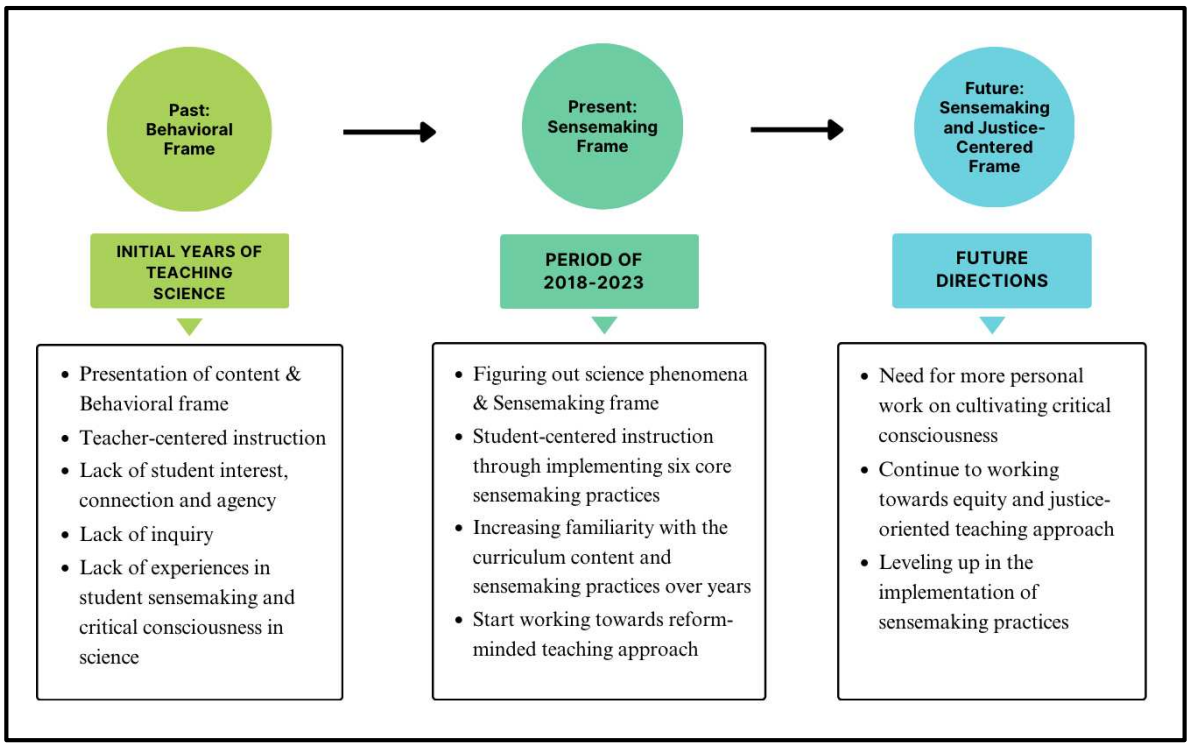
CHAPTER 6: DISCUSSION AND CONCLUSION

What Was Learned about the Changing Teacher Practice and Student Sensemaking?

Earlier, I addressed the explicit changes that occurred in Ms. Spark and her students' implementations of sensemaking practices across the years. I provided excerpts of students' small and whole group discussions, as well as their exemplary work (artifacts, models, CER charts, and DQBs) to interpret how the implementation of these practices supports students' sensemaking experiences over the years. Following, I discuss the main takeaways for us (as teacher educators and researchers of science education) in investigating the changes in teacher's practices and students' sensemaking experiences.

Figure 23 below represents critical summary points from my analysis. I also support these summary points by providing insights from Ms. Spark's own reflection when she talked about the changes, she experienced by implementing practices and curriculum materials over the years:

Figure 23. Ms. Spark' Developing Trajectory in Teaching Science through the Changes in the Implementation of Practices



Before using ML-PBL curriculum and implementing sensemaking practices, Ms. Spark used a curriculum that was more teacher-centered and lacked in supporting students'

sensemaking experiences. She referred to that period by saying "*The kids were struggling… I could see I was losing them because it was a lot of stuff was just thrown at them… It wasn't differentiated for different learners... I wasn't engaging the kids, and they weren't excited about coming. I was like do a lot of like demos and he kept everything really short."* Therefore, her initial science teaching career mainly involved presenting and instructing content without leveraging student discourse and collaboration, as well as without promoting critical consciousness and different ways of engaging with and making sense of phenomena. Since the main materials were videos and demonstrations, students did not wonder, experience, or figure out phenomena. She stated that the inquiry piece was missing, and students were not interested in learning science. Her approach mostly utilized traditional practices of teaching science where students lack sensemaking experiences and critical thinking toward phenomena.

During the period of 2018 and 2023, Ms. Spark implemented sensemaking practices using ML-PBL materials. A shift to the use of sensemaking practices was observed as she became more familiar with the ML-PBL materials over the years. I observed her teaching practices change from a traditional approach to a reform-based approach. She moved away from teacher-centered direct instruction, where students are expected to behaviorally engage and perform based on the teacher's directions. As she implemented sensemaking practices, I can infer a shift from a student-centered to an inquiry-based approach where students become active participants in their sensemaking experience by noticing and wondering, experiencing, predicting, critiquing, explaining, and eventually figuring out the phenomena.

As Ms. Spark and her students utilized sensemaking practices (such as using DQ and DQB, various discourse moves, multimodal representations, and collaborating with their peers), I observed differences in a) students' sensemaking experiences as they collectively critique, represent, and co-construct knowledge, and b) Ms. Spark's teaching approach and dedication to become an innovative and reform-minded science teacher.

Reform-minded teaching refers to the approach that uses guidelines (see Figure 3) of working towards equitable and justice-oriented learning environments (as one of the core sensemaking practices). The analysis provides evidence that Ms. Spark adopted an *asset-based mindset* in her interactions and relationships with her students over the years. In doing so, she consistently worked to know her students and their families' cultural background and resources, as well as she affirms the value and contribution that each student brings into the science

classroom. She positioned students as builders, doers, and critics of knowledge. She worked wholeheartedly to build *positive and humanizing relationships* with her students and their families by incorporating their cultural experiences and stories to science. Her following insights support that:

> *Bringing the family connection really helped, so student can have conversations at home. It gives them the incentive to learn more what they're learning here. It also encouraged parents to plan trips. I've had a lot of kids talk about going to bird sanctuaries after this. Then, I've had a couple occasions where a parent or grandparent will email me and say: Hey, we understand the kids are talking about birds and we've had this bird feeder, and we got this bird that's come to our feeder. So, it's not like science is some scary subject that they can't share with their kids, that they feel like they got some kind of connection to the school.*

She also worked towards supporting students' *social-emotional learning (SEL) experiences.* To meet the equity and SEL goals of the lessons, she worked with students to help them develop science interests and take ownership of their ideas. She indicated that: *"I was feeling like, this is the way to go, because they were learning from each other and wonder about stuff and try to figure out why. They were like taking ownership in it. It almost felt like they were doing the lessons themselves".* Ms. Spark was also mindful to shift the position of power and authority from herself to students and multiple stakeholders, especially to parents and other family members as she invited them to the sensemaking process. From all these angles, I argue that Ms. Spark's practice evolved during the period of 2018-2023, because she frequently and mindfully used sensemaking practices, utilized the curriculum materials, and set her priorities towards supporting students' sensemaking and SEL experiences.

Finally, to discuss future directions in the continuum of her shifting teaching practices, I chose to have number of conversations with Ms. Spark where I asked how she would portray her future science teaching considering the hopes and inspirations she has. She first shared how she feels and identifies the positive changes in her instruction over the years:

> *I feel like I have grown a lot over years. I feel like not just as a science teacher, but a teacher that allows kids to take some leadership and ownership. It's fun to watch them kind of blossom… I also think as the kids get more comfortable figuring things out themselves, then I feel like it's easier for me to teach and get through the lesson because we're all more familiar with the routine of how to figure things out.*

Then, she took a critical and honest approach to reflect on what challenges she had and in what areas she needs to put more critical work to strengthen her future practice:

But there were moments like the Tree Lesson... I would not have thought of it myself. If I hadn't done that lesson with equity lens and really look at like what environmental issues are... If I am not thinking and asking about it obviously, they're not going around and thinking about these critical issues… I guess it kind of just builds critical awareness of how other people and communities might be going through some hardships and injustices that you don't really know about or that you're not exposed to, because they just are thinking in their own little world right here.

Agreeing with what Ms. Spark suggests above, I see room for development in terms of guiding students to *develop critical consciousness* in identifying and critiquing the existing socio-cultural, racial, and environmental inequities and injustices related to issues in science and society. In number of lessons (see Snapshot #6). Ms. Spark showed initiative to introduce students to critical concepts, cases and examples. However, the discussions of these lessons remained superficial in the sense of reaching to the point of where students start thinking about the unbalanced power relations, normalized deficit views about and experiences of minoritized communities, or stereotypes that takes place in the process of doing, disseminating and being a part of science. Therefore, I argue that there were missed opportunities in building further collaboration and communication between Ms. Spark and us as researchers, since Ms. Spark wasn't able to be a part of the PL community after 2020. Since there wasn't ongoing critical work and reflection on how to explicitly name, address, and converse about these critical issues with children and how to teach about them, I infer that Ms. Spark did not necessarily center these justice-centered issues and questions in a deeper manner.

Second, her own remarks above raise an important point. Even though she started to work with students to raise consciousness about critical phenomena to some extent, she acknowledged that she needs to put more critical self-work on grasping a) what inequities and injustices exist in the community of science and b) how justice-oriented science teaching looks like in elementary classrooms. She knows that without her initial thinking and critical self-work on these issues, it is challenging to facilitate discourse and navigate these hard questions with students. I think this is the level of self-awareness that we hope and expect from teachers in the beginning of this ongoing process, especially for teachers from rural backgrounds and White communities. It is critical for them to understand their whiteness in the context of the US and include narratives and realities of multiple local and global communities. Therefore, the overarching future goal for Ms. Spark, teachers and teacher educators is to move beyond surface-level thinking and start asking

why systems and practices exist and how these are connected to complex historical, political, cultural, and social values and practices.

The other critical point for this study is discussing students' experiences in making sense of scientific phenomena. I am eager to discuss how Ms. Spark and students' implementation of sensemaking practices would actually impact or support students' sensemaking experiences along the way. To do so, I mainly reflect back on and interpret students' work and their verbal exchanges through my analysis (Table 8) and indicators of students' sensemaking experiences (Table 5). The analysis indicates that a) students actively engaged with sensemaking practices throughout the three year period, and b) similar to Ms. Spark's trajectory, students' implementation of the practices also developed and become more sophisticated over the years in terms of wondering, noticing and experiencing phenomena using first and second hand resources; developing meaningful and relevant sub-DQs in relation to phenomena; using evidence to develop Claim-Evidence-Reasoning (C-E-R) cycles; and having critical conversations and reflections towards critical and cultural phenomena. Figure 24 below represents a summary of how and to what extent students engaged in sensemaking experiences (through student work and exchanges) over years:

Figure 24. Indicators of Student Sensemaking Experience between the Years of 2018 and 2023

During the **2018-2019** school **year,** students started to actively wonder and notice phenomena. They showed curiosity towards phenomena through the questions they asked and the experiences they brought into the conversation. With the encouragement of Ms. Spark, they asked additional open-ended sub-DQs in relation to phenomena and added them to DQB. Within their small group investigations, they start forming claims, explanations, and reasoning (CER) chains in relation to scientific phenomena. Joey and Carol's pair work (see Figure 9) was representative of how they and most other students form drawings and explanations in relation to phenomena. That work shows how students mainly picked up ideas from the videos without necessarily using their observations from them to support their explanations.

Similarly, Jonah, Roman and Philip's group work also illustrates that even though students worked collaboratively to find and test their toy designs, their use of evidence and reasoning to explain the motion remained superficial (see Figure 15). Therefore, there was room for development, especially in terms of their use of discourse and evidence to support and explain claims. In terms of the final indicator of sensemaking, there were missed opportunities for students to critically reflect on the equity, justice, and community aspects of the phenomena since there were not many discussions raised by Ms. Spark around the justice implications for the environment and communities. Based on these points, I argue that students engaged in sensemaking to some extent in line with the quality and frequency of the sensemaking practices they used. Their sensemaking experiences could be more nuanced if students had a chance to engage more in the processes of *e*xplaining how and why the identified phenomena occur and explore and critique how the scientific phenomena have justice implications for the environment and communities.

In the **2021-2022 school year,** students' sensemaking experiences become more visible based on the indicators. Students actively showed interest and investment by wondering, noticing, experiencing, and predicting on an overarching phenomenon. In doing so, I observed them using and building multimodal representations (models), using verbal and non-verbal language, such as gestures, drawings, skits to express and discuss their thinking, and building explanations towards the phenomena and DQ (see Figure 10 and Table 9). For example, Figure 10 and Figure 11 show group work that address how the stegosaurus couldn't meet its needs, but the Juramaia (Eutheria) could because of how the environment was slowly changing and the Eutheria was adaption to the changing life circumstances. Their skit, drawings, labels, and verbal

and written explanations on their models, illustrates a sophisticated and meaningful Claim-Evidence-Reasoning (C-E-R) Cycle in their effort for making sense of how climate and the environment changed during the Jurassic period and caused some animals to die out while others survive. Their models also show evidence on how they started connecting the phenomena to their lived experiences, by connecting Juramia to Squirrels considering the changing world, climate, and resources they have now. During this year, students' use of DQB (see Figure 17) and discourse moves (see Table 8) also increased and varied, which eventually supported them to bring further explanations to their claims. It also encouraged them to bring their own personal and cultural connections to phenomena (especially within the outdoor observations and falconry session in the Bird Unit).

In the **final year of 2022-2023,** I observed how students engaged and worked towards almost all the indicators of sensemaking. Students actively wondered and noticed phenomena based on their observations of nature (e.g., outdoor wonder walks) and community (e.g., family interviews). They made references to the DQ using their previous investigations and their own ideas and experiences. They frequently added questions to DQB and integrated some of their own sub-DQs to the discourse in the pathway of making sense of phenomena. The quality of their verbal and written models and artifacts also peaked in terms of forming accurate claims, explanations, and reasoning. They used a variety of different types of evidence (i.e., theories, empirical data, personal and cultural stories, and experiences) to describe and support the claims. For example, Figure 13 includes a sophisticated series of student models on focal bird's life cycles. Students advanced their models by bringing evidence to their explanations and addressing the points they collectively raised in their consensus chart (see Figure 12). With the accurate, detailed, and evidence-based claims, use of evidence and reasoning (C-E-R), these models and explanations were the most nuanced, sketched form of expressions that students created over the years.

Most importantly, students started exploring and critiquing how the science phenomena or events had justice implications for the environment and their communities. For example, within the discussion on the news article of "Trees grow on money", students started to have critical discourse on a) what equity might mean, b) how some communities have more trees than others, c) what might be the effects and reasons of such an inequity, and d) what critical action they could take to address these environmental injustices. This initial critical thinking became]

possible as students heard about these issues and were exposed to the critical questions to discuss them. They reflected on how equitable planting goals are needed to design solutions for underserved areas and communities. Even though there were missed opportunities to dig more into justice and system-level implications and design solutions especially for marginalized communities and nature, students showed interest and initiative to explore and critique the phenomena using a critical lens. They also consistently connected the science phenomena to their lived experiences, family, and community resources, especially through the discourse on the read-aloud of the story of Mary Anning (see Figure 18), story of Lonnie Johnson (see Figure 21) and sharing of the family stories about local birds (see Figure 22).

Within all these discussion points, I would like to go back to my initial arguments for this study. As I hoped and aimed, the discussion of the in-depth analysis shows that these six sensemaking practices can a) support teachers in working towards reform-based science teaching and learning practices (therefore, transform their identities), and b) support students to engage in and reach equitable, relevant, and critical sensemaking experiences in learning science.

Potential reasons for the critical changes in Ms. Spark's implementation

In 2018, I started to observe Ms. Spark using new perspectives and practices. Until the period of 2023, I continued to observe Ms. Spark using inquiry, project-based, and reform-minded sensemaking practices. Due to this shift in her teaching practices, it appears that she went through a series of changes in her mindset and implementation of sensemaking practices in teaching science. Besides identifying the changes, it is equally critical to delve into the potential reasons for those changes in her practices as a part of her developing teacher identity. Knowing the personal, professional, and curricular context of Ms. Spark's teaching, I argue that one reason for the changes in her implementation might be connected to a) participation in professional learning (PL) sessions that were provided by ML-PBL team in 2018 and 2020. Alternatively, we can argue that her collaboration with me (through our ongoing formal and informal conversations) especially during the year of 2022-2023 might lead her to prioritize equity, SEL and justice-oriented phenomena in facilitating the discussions. Finally, her positionality as a person and a professional might be an alternative explanation of what and why she values and prioritizes certain practices in science learning and teaching.

As I specified earlier, Ms. Spark attended professional learning (PL) sessions throughout the school years of 18-19 and 19-20 before the pandemic hit. In these sessions, Ms. Spark had a

chance to work with a number of researchers and teachers by discussing the ways of supporting students in making sense of phenomena in science, the main features of PBL, and the scope and goal of the Units. In these sessions, researchers and teachers also worked together to discuss and negotiate the ways to create equity-oriented classroom environments that affirm cultural identity, responsible ownership, and collaborative productive relationships.

More specifically, ML-PBL researchers worked with teachers to support their learning to enact the curriculum which aligns with PBL features to support students in figuring out how to make sense of phenomena and design solutions to problems. Researchers established the features of PBL as a) pursuing solutions to meaningful driving questions, b) using big ideas to frame 3-D learning goals, c) exploring the question by participating in scientific practices to "figure out" why phenomena occur and learn important ideas in the discipline, d) collaborate with others to find solutions, e) scaffold learning to help students participate in activities and f) create artifacts that address the driving question and represent student knowledge. To experience and discuss these features, teachers worked in groups to build the final artifacts of each Unit to see the coherence of the unit and opportunities for sensemaking about big ideas of ML-PBL. They had in-depth conversations with their colleagues about the proposed integrated approach to reading, writing, listening, and speaking (i.e., discourse moves), and mathematics in the curriculum. In addition, they explored together the changing role of the teacher in supporting collaboration as a vehicle for deep, flexible understanding of big ideas and science. In a way, Ms. Spark discussed several components of the sensemaking practices and became familiar with the content of the ML-PBL curriculum.

In one of the PL sessions, ML-PBL researchers encouraged Ms. Spark and other teachers to think critically about the questions of how learning builds over time, how students can use knowledge built over time to develop models, and what students can develop as a final artifact. The researchers intentionally raised these critical questions to support teachers in figuring out that the DQs in lessons help students build ideas over time coherently. As students build explanations of the phenomena in each lesson, that would lead them to figure out the overarching DQ and support them to develop their final artifact in various forms. To grasp what counts as various forms, teachers discussed different ways of expressing and explaining phenomena, such as stories, narratives, skits, sketches, or models. These conversations on multimodality appeared to impact Ms. Spark's approach to bring equitable modes of modeling and artifacts as multiple

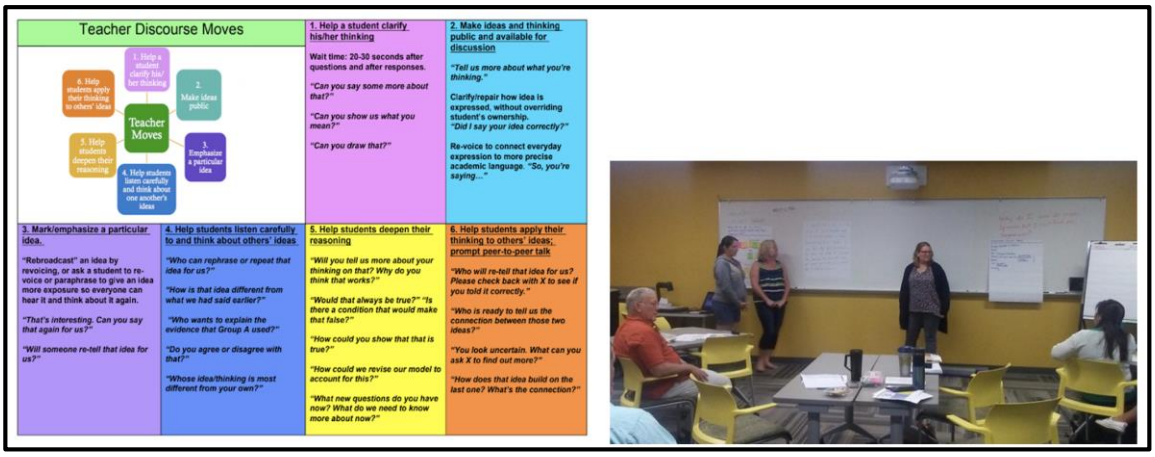
ways to figure out phenomena. In these PL sessions, there wasn't an explicit and specific focus on how to support students in creating skits and using gestures and drama. Nevertheless, Ms. Spark adapted these ideas to her own classes as she worked with her students to support their needs, interests, and preferences in explaining phenomena. Therefore, I argue that PL sessions provided initial strategies to trigger the critical shift on incorporating equitable ways of explaining and expressing phenomena.

Another critical point from the PL sessions was that the teachers consistently discussed what counts as a model, what components the model should have, and how important evidence is in building, and explaining the models and claims. The consistent exposure to these ideas about modeling and the importance of evidence most likely supported Ms. Spark's change in terms of a) working with students to build individual and consensus models, and b) reminding students to use evidence to support their claims and models. On the other hand, especially within the year of 2022-2023 (when she wasn't participating in the PLs), she shifted her focus to what counts as evidence and what different resources can students use while gathering and using evidence. One potential reason for that might be our (me and her) ongoing discussions on different ways of exploring and explaining phenomena, introducing multimodal approaches in building models and artifacts, and how to involve students' family and cultural resources as a tool and evidence to relate, explain and make sense of phenomena. Therefore, she also kept adding to her pedagogical toolbox and repertoire as students had more experiences outdoors and brought their family resources and stories to science. These experiences possibly became another critical venue for students to discuss the variety of evidence and use of evidence.

Ms. Spark stated that one of the most valuable aspects of ML-PBL and sensemaking practices was leveraging discourse among students. She stated that discourse allows students to take leadership and ownership of their own learning as they discuss, explore, and co-construct knowledge together. One possible reason for this realization was the PL sessions since there was an ongoing focus on what counts as discourse, why it is pivotal, and how to leverage that among students. ML-PBL researchers introduced both teacher and student discourse moves as a reciprocal act and process where teachers and students have critical discussions in co-constructing knowledge. For example, the researchers shared the potential ways to promote discourse in classrooms by unpacking the chart (see Figure 25). As I observed how Ms. Spark's way of setting and facilitating the norms of discourse changed over time, I argue that these

exchanges might have developed her practice towards discourse. Another possible reason for this change is because she had more practice with discourse mores and observed that children would interact more when used discourse moves.

Figure 25. Ms. Spark's Participation to PL Session Using the Discourse Moves Chart



In the 2019 - 2020 PL sessions, ML-PBL researchers focused on a) how to shift from *learning* to *figuring out* and b) how to integrate students' family resources and SEL experiences into science instruction. To do so, they facilitated a number of discussions where Ms. Spark and other teachers presented their ideas about how they can go from learning about to figuring out. Teachers were introduced to the process of figuring out and making sense of phenomena as a means of "students collaboratively using evidence to predict or explain a phenomenon or solve a problem in the natural or design world." Even though this sensemaking definition does not capture all the cognitive, social, and cultural aspects of my sensemaking definition (and therefore sensemaking practices), it could serve to guide teachers about the importance of using evidence, predicting, and explaining phenomena during science lessons. This aspect of *figuring out* most likely informed Ms. Spark's practices as she moved away from a behavioral frame to sensemaking frame (see Snapshot #1). The second year of PL experiences also might have supported Ms. Sparks' changing practice because in the PL sessions, teachers were observed reinforcing the ideas and practices of how to facilitate and center family interviews, interactive read-aloud, and SEL and equity goals in each Unit. I observed the growth in all these aspects of instruction during the 2021-2022 year. Therefore, I argue that the shifting focus on the PL within 2019-2020 year might have reinforced the shift in Ms. Spark's instructing in terms of making family connections and SEL experiences more visible.

Although PL sessions might be considered a main contributor to those changes, it is also important to realize that she wasn't able to attend any PL sessions after 2020. Therefore, I take a different approach to discuss the sources of those changes in her implementation for the year of 22-23. In the final year, I observed practices that indicate she took a more critical lens to SEL and equity-oriented lessons. One reason for this change is that I chose equity and SEL lessons to observe to learn more about her approach to teaching these types of lessons. Since she wasn't working with other ML-PBL researchers and teachers during that year, I became her collaborator in terms of reflecting on the critical aspects and learning goals of these focal lessons. We discussed potential questions for navigating critical conversations on the existing inequities and injustices in nature, science, and society.

Before each lesson, I had brief conversations with her about a) her interpretation of the equity and SEL goal, b) her perspective on critical and cultural phenomena, and c) the ways to facilitate critical conversations about these issues. After each lesson, we also had a brief follow-up conversation on what worked well or not or what were missed opportunities and ways to make the critical discussion better. These open and honest reflections potentially encouraged Ms. Spark to think and reflect further on how she could improve her instruction on these issues. I argue this because, before the Tree Lesson, we had some provocative dialogue on why some communities in Detroit don't have greener areas and how this inequitable planting scheme has environmental and medical consequences for the people of color considering the Detroit population. After our conversation, I heard Ms. Spark asking questions of what equity might mean and how different communities might be affected by these inequitable planting goals. Interestingly, these questions weren't included as suggested prompts in the curriculum materials. Therefore, she incorporated some of the core points from our dialogue and used them to adapt/modify the critical discourse. In another example, before she facilitated the read-aloud on the book of "*Four Feet Two Sandals*" in the Bird Unit to address and bridge human migration to migrations of Birds, I shared with Ms. Spark how this story resonated with me as an international scholar who keeps traveling between home and other countries and how other people move from their homes and migrate in variety of different reasons. As I shared my experience and my curiosity about if she has any other students with global connections and experiences, she made sure to ask questions to invite students to share their global experiences. Her questions invited one of the students whose family migrated from India years ago to discuss his background. The

conversation visibly strengthened the participation and various ideas and experiences of the students. These are some of the examples that potentially show how our shared experiences and shared motivation helped work towards cultivating critical consciousness in Ms. Spark's classroom. Therefore, I argue that having a consistent partnership and collaboration between teachers and teacher educators is essential in supporting teachers to think about critical and alternative ways of thinking and doing science. Our collaboration potentially led to classroom discourse where students start thinking about equity, justice and global contexts and experiences.

As a final potential critical source for changing teacher practice, I would like to address Ms. Spark's *self* and *conceptions* on science learning and teaching. On several occasions, she shared how she values getting to know students and their families to better connect with them and bring their cultural resources to science. This passion of hers may have shaped her practice and led to a valuable modification and addition to her science teaching over the years. Originally, the ML-PBL curriculum did not involve any specific lesson where students' families joined to facilitate the lessons in the Bird Unit. She invited students' families, specifically Ted and Nina, to her classroom for consecutive years while teaching about birds. The Falconry lesson became a signature lesson in the entire school as other 2nd and 3rd graders, teachers and administrators also joined one of the most engaging and interactive Bird lessons. Through this modification, students had first-hand experiences by seeing various birds and figuring out the life cycles, stages, and characteristics about them in their various habitats.

Ms. Spark's participation in PL sessions, my exchanges with her during 2022-2023 period, and her positionality and conceptions as a growing reform-minded science teacher may have worked together to reinforce changes in her practice to teach science. These experiences may also have informed how she adapted and modified some of the curriculum materials, such as in building, explaining, and presenting models in multiple modes; amplifying family and community resources to science; and raising critical discourse questions to make students further identify and critique existing inequities in science, nature, and society.

The Relationship between the Components of Teacher Identity

I approached the notion of teacher identity by proposing a model to embrace the individual, and collective and systemic-level experiences of a teacher. In addition, I bring a specific and central focus on their practice-level experiences by investigating if or to what extent a teacher would implement pedagogical and instructional practices that are informed by or would

inform these individual and collective experiences. I argue that these different levels of experiences cannot be considered separately and that they contribute to our understanding of how we can make sense of teacher identity and what it holds.

More specifically, knowing that identity is a complex construct to capture and operationalize, I draw from a variety of critical perspectives and work of learning scientists, science education researchers, and social psychologists. I focus on the question of how identity scholars in science education decide to operationalize and study identity development. Through the social and cultural aspects of teaching and learning setting—which includes patterns of various teaching and learning activities and practices, individual and group-level interactions, and the meaning-making process—I was able to investigate what shapes a teacher's behavior, values, and sensemaking experiences of students in the group.

In building my teacher identity framework, I was careful and intentional in setting the methodological preferences to study identity as more than an individual construct as well as taking into consider a teacher's experiences and interactions. In the literature, identity is mostly operationalized and connects to micro, meso, and macro levels of educational contexts (Foucault, 1976; Wade-Jaimes & Schwartz, 2019). Within the individual lens, I was able to delve into the micro-level experiences of the teacher and explore the questions of: What did the Ms. Spark and students do? How did they implement the sensemaking practices and what changes are we able to see in their pattern of implementation? What was Ms. Spark's previous pedagogical and content knowledge and personal background?

These questions were relevant to understand a part of what went well, what was working and what was challenging for Ms. Spark and her students (as they start to use more innovative and reform-minded practices), but without taking into account Ms. Spark and her students' prior and current knowledge and practices within the complex institutional, organizational, societal, and historical systems and structures. I acknowledge that a theory of knowing, learning, being in identity work that focuses only on individuals is falling short for explaining how and why reform-minded shifts in teaching and learning fail or succeed (Carlone, 2022; Johansson & Larsson, 2023).

To bring a critical, systemic, and macro-level perspective, I took an approach by attending to connecting identity work to different levels of systems. I specifically highlight and investigate what collective and systemic level experiences Ms. Spark engaged in over the years

as a critical component of her identity development. In doing so, I also started asking and analyzing not only "Do Ms. Spark and her students follow sensemaking practices?", but also "What does it mean to implement sensemaking practices for teachers and students in their context and setting?" and "What structures make Ms. Spark invested and interested in developing those practices in her classroom?"

I now connect back and investigate a) Ms. Spark's experiences, knowledge and stance on previous and current curriculum resources, b) Her partnership and collaborative work with the ML-PBL researchers through PL sessions, and with me through one-and-one coaching experiences as she works towards developing reform-minded practices, and c) her relationship with her administration, fellow teachers and parents of her students in the decision making process of implementation of practices and adaptation of curriculum.

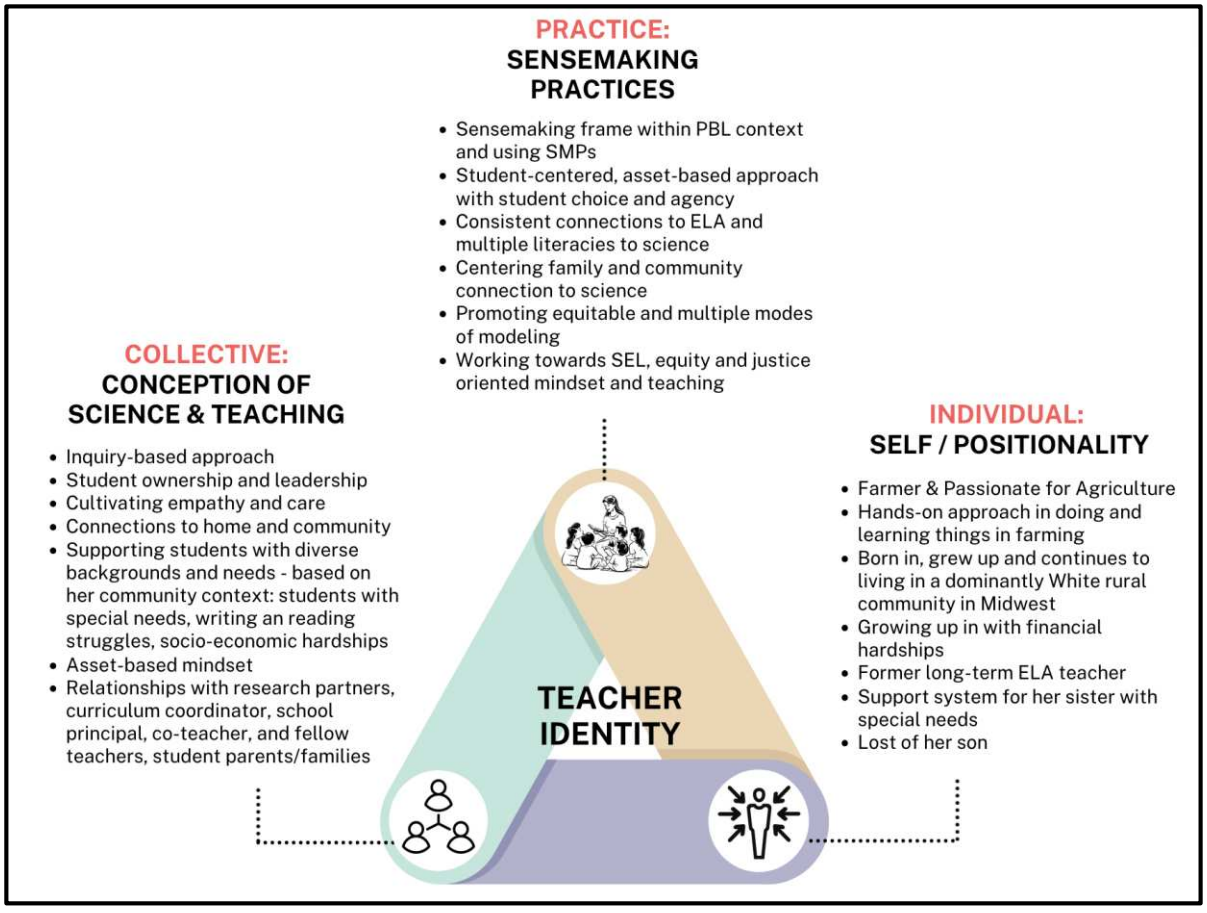
Delving into these system-level relationships in identity work allowed me to bring a macro-level approach and represent the history of Ms. Spark's participation and development in teaching and learning. In doing so, I prioritized the question of "How does working towards innovative and reform-minded elementary science teaching in this particular social and institutional context connect to Ms. Spark's identity trajectory up to a larger network and systems? How does Ms. Spark challenge or reproduce status quo meanings of promising and critical science teaching and learning?

The core findings of the study helped me address to these questions. The evidence shows how Ms. Spark's ongoing work within the institutional, community and research-based collaborations and partnerships (within ML-PBL researchers, teacher leaders and curriculum developers) challenged her initial way of seeing and practicing science and science teaching. The evidence also shows she prioritizes focusing on connecting to students' family and cultural resources and centering the discourse on critical and cultural science phenomena. The interactions and support that Ms. Spark had within the collective system are one possible reason that enabled shifts in her practice and identity development. These critical shifts in Ms. Spark's identity trajectory could be supported through this system-level research collaborations and the institutional context of her classroom/school through the relationships she built with experts, researchers, curriculum developers, fellow teachers, and student families.

I also argue that the particular and explicit focus on practice within those individual and systemic complex structures can make a unique contribution to identity work because I prioritize

and center teachers' and students' practices (pedagogical and instructional practices) as they teach and learn science. The analysis indicates that Ms. Spark's individual experiences and who she is strongly connect to her conceptions and implementations of science teaching. Her way of interacting and communicating with multiple stakeholders around her informs how she negotiates and transforms the practices she enacts in their own classrooms. Figure 26 provides an illustration of how Ms. Spark's individual, collective and practice-level experiences connect to and inform each other. It also provides a holistic picture and understanding of what critical components and experiences we can consider while trying to make sense of this complex, fluid, and ever-changing notion of teacher identity.

Figure 26. The Interconnected Nature of the Individual, Collective (Systemic) and Practice Level Experiences of MS. Spark's Teacher Identity



For example, as a farmer who reported a passion for agriculture, serving her small community through farming and teaching could help explain who she is and how she identifies herself as a person. Her farming experiences might explain why she used and adopted a hands-on

approach to doing, experiencing, and figuring out events in her life. Holding such a perspective finds a place in her conception of science teaching through an inquiry-based approach where students can experience and investigate phenomena and build artifacts in the process of explaining and making sense of phenomena. Having such a vision in science teaching provides one possible reason that makes Ms. Spark dedicated and excited to implement sensemaking practices.

From another perspective, growing up with financial hardships and living in a rural and predominantly White farming community might have shaped Ms. Spark's positionality to become a central connecting point in her community. Since her students and their families are members of this community, most of them have a similar cultural background as she does. Therefore, while addressing the diverse backgrounds and needs of her students, as well as her approach to equity and justice-centered science teaching, she mainly referred to students with special and socio-economical needs and supported students who struggled with writing. Her positionality is one potential reason that might have shaped her conception of what an equitable science classroom might and should look like based on her familiarity with the context. As she joined the PL sessions, collaborated with researchers and fellow teachers, became exposed to new curriculum materials, and had ongoing conversations with me on how SEL, equity and justice-oriented science education might look like, she started taking a step forward to understand their whiteness and localized view of diversity. She started thinking about unbalanced power issues, normalized deficit views on minoritized communities, and stereotypes that take place in the process of doing and being a part of science. This shifting conception may have helped transform her practice as she taught the lessons on Trees, family interviews, and the story of Lonnie Johnson. She left with a note that she needs more critical self-work to raise her own and students' critical consciousness in science.

Ms. Sparks reported believing in the importance of family and experienced several hardships with close family members, helps to understand why Ms. Sparks values home and family connections when teaching science. The traumatic loss of her son and the hardships that her sister went through may have helped her realize how empathy, care, and an asset-based mindset became the core components of her ideal science teaching environment. I was able to see her conception inform her practices when Mable shared the special meaning the Cardinal had for her family members because of a family loss. In that class, Ms. Spark was open and

vulnerable in sharing about his son and how she connected this experience to certain birds, too. She later shared with me that these exchanges encouraged some other students to share their own family stories. Similarly, a potential reason why we were able to see the Falconry lesson was her commitment to building positive relationships with students' families and inviting them to a class as experts in the science learning process. This case helps us understand that when a teacher cares and prioritizes home, family, and cultural connections to science, we are more likely to see how this dedication transforms into the classroom and most likely supports students in SEL and sensemaking experiences.

After seeing these potential connections, it is quite remarkable how Ms. Spark's changing practice in the classroom and her statements (when she talks about her individual and collective experiences) illustrate a coherency among different aspects and levels of her science teaching. In other words, how she portrays who she is and her conceptions of what science learning and teaching should look like aligns with how she approaches curriculum materials and teaches science. These aspects are also coherent with how she has certain expectations from the members of her community, especially in her interactions with the principal, in her way of working with her colleagues, and in her expectations from PL sessions and research partnerships. This coherency and the interconnectedness in Ms. Spark's honest remarks supports my initial argument: it is impossible to provide a holistic and realistic view of teacher identity development without at least attempting to consider multiple levels of personal experiences, conceptions, and practices (Carlone; 2022; Daniel, Pierson & Keifert, 2023; Giralt-Romeu, Liesa & Castelló, 2024; Krist & Shim, 2024).

Overall, through this collective systemic approach to identity, a picture arises of how classroom, institutional, and historical practices, negotiations, and arrangements, such as normative ways of doing things, work together to make more likely the cultural reproduction and development of the teacher identity. Therefore, the main takeaways are that science educators who take a more critical or sociocultural lens when studying teacher identity over time share commitments to (1) considering how context and resources cultivated in one setting are leveraged in other settings within the partnerships among the multiple components of a larger system (i.e., schools, teachers, and researchers); (2) considering how an individuals' identity pathways are uniquely constructed but also heavily affected by systemic structural arrangements and negotiations; and (3) avoiding artificial and superficial linearity in understanding identity

work over time within the consideration of how individual's identity pathways, their collective experiences within systemic level and their practices work holistically as a whole system.

Implementations and Contributions for Research, Teacher Education, and Curriculum

The work of understanding the ever-changing, fluid, and contextual nature of teacher identity is a complex and multi-layered effort because a teacher has a positionality, conceptions, and practices of science and science teaching based on their ideas, values, and prior experiences. Considering this complexity, I looked for ways to capture, interpret, and make sense of a teacher's changing identity trajectory in teaching science. I specifically focused on the teacher's a) personal prior life experiences and histories, b) conception of science learning and teaching, and c) implementation of sensemaking practices to illustrate a holistic picture of such transformation.

The study presented the journey of an experienced teacher, Ms. Spark, as she developed a reform-based mindset in teaching elementary science using PBL-oriented curriculum materials and sensemaking practices. During this journey, she formed a number of relationships with multiple stakeholders in her community that connected with her and her shifting conceptions and practices of science teaching. In her initial years of science teaching, she did not appear to have a defined framework of science teaching and did not use teaching practices that focused on sensemaking, equity, and justice. Therefore, this study indicates the importance of how the previous and changing frameworks and conceptions of science teaching work together and inform the decision of the teacher while choosing what teaching practices to use and how to implement them based on the school and community context (Matias, 2013; Thompson et al., 2013).

Aligning with the previous studies (e.g., Kavanagh & Danielson, 2020; Mensah & Jackson, 2018), this study also presents some evidence of how important it is for teachers to engage in critical self-reflection and critical self-work in the process of cultivating critical consciousness in science and science teaching (similarly, in the process of developing reform-minded teacher identities). Ms. Spark's case provides evidence of how her constant effort in interpreting, reinterpreting, and negotiating the changes she went through initiated and supported her transformation throughout the years. In other words, because of her dedication and involvement in using sensemaking practices (as a pedagogy and strategy), we see how she supports students in sensemaking and, more importantly, how she sees the importance of equity

and justice-centered work (Cochran-Smith & Villegas, 2016). Another possible explanation for this occurrence is because Ms. Sparks was trying to help me as a young researcher, so she implemented the lessons as we discussed.

In addition, this study adds to our knowledge on the ways of supporting elementary students' in making sense of phenomena and raising their critical consciousness towards critical and cultural phenomena. In line with the previous literature, this study also some provides evidence that the use of productive discourse becomes a critical tool for sensemaking as students wonder about phenomena and use reasoning and evidence to co-construct scientific knowledge (Benedict-Chambers et al., 2017). The data also seems to indicate that students and teachers' reciprocal use of discourse prompts supports students in building claims based on evidence and aids in their language literacy to communicate and disseminate their ideas (Carpenter et al., 2020; Snow et al., 2022). The study also provides evidence that consistent use of diverse sensemaking practices and repertoires encourages students to identify, predict, explain, and critique scientific phenomena while using various representations and perspectives (Kyza, Constantinou & Spanoudis, 2011; Lin et al., 2012; Rosebery et. al., 2015).

The data of Ms. Spark's work with students in building multimodal artifacts also appears to indicate how equitable and multiple modes of modeling become an epistemic tool that leverages student engagement and critical sensemaking (Sezen-Barrie et al., 2020; Schwarz et al., 2021). This study provides a case for what equitable modeling could look like (within contextual artifacts, such as explanatory models, skits, drama, gestures, and investigation graphic organizers) and how using various representational systems and means of expression may be instrumental for making sense of phenomena (Schwarz et al., 2022). Students' multimodal, artful, and creative models and representations from the snapshots of this study, as well as the family and nature involvement in the sensemaking space, aligns with the literature arguments on using various epistemic tools to expand diverse ways of knowing (Krist, 2020; Reiser et al., 2021; Rosebery et. al., 2015).

Furthermore, this research suggests critical implications and contributions that can be specifically organized into three areas: teacher preparation, theory and research, and curriculum development. In terms of the implications for teacher educators, I argue that sensemaking practices can support pre-service and in-service elementary teachers in learning to teach science in a sensemaking, equity, and justice-oriented vision. The sensemaking practices provided a

mindset and set of pedagogical guidelines for the teachers where they can leverage equity and justice-oriented, humanizing approaches to science teaching in defining, redefining, and implementing their teaching practices. For university level elementary science teaching methods classes, sensemaking practices can be incorporated into the content of each week's session. For in-service elementary teachers, sensemaking practices can be leveraged as teachers are introduced to and discuss the ways of incorporating those practices in their own contexts and science classrooms within sustained professional learning opportunities and support. Another potential supplemental point to foster and contextualize sensemaking practices is using high-quality and critical elementary science curriculum materials that would align with the vision and goals of sensemaking and equity-oriented science instruction (such as ML-PBL as an inquiry and project-based quality curricular context for this study). Therefore, the incorporation of sensemaking practices with high-quality curriculum materials and consistent professional learning opportunities will become critical for the practitioner and teacher educators who utilize these ideas.

In relation to the theory and research on teacher identity, this study aligns with the previous research and provides additional evidence that teacher's personal histories and their values on what constitutes an ideal science learning and teaching space inform their conception of teaching science and, therefore, their science teacher identity (Avraamidou, 2020, Holland et. al., 1998; Lave & Wenger, 1991). From this perspective, this study suggests the robust existing research on how science teacher's histories, perceptions, and conceptions of teaching science shape their developmental trajectory of identity (BouJaoude, 2000; Crawford & Cullin, 2004; McDonald & Songer, 2008; Taylor & Booth, 2015). However, this study takes a step further and brings a core contribution to the field by proposing a holistic and multilayered framework to define, capture, and interpret teacher identity development. Drawing from Holland et al.'s (1998) theory of *identities-in-practice*, I proposed a framework (see Figure 1) to capture the development in teacher identity by addressing the teacher's personal histories and positionalities as an individual, their multiple and evolving conceptions in teaching science based on their relationships and negotiations with their larger teaching community, and most importantly, their implementation of teaching practices to support students in learning science. The study provides evidence that teacher's personal histories, conceptions on teaching and learning, and implementation of practices are closely connected to each other and impact one another in the

process of becoming and in negotiating identity development (Avramidou, 2016; Carlone et al., 2015; Nasir & Cooks, 2009; Søndergaard, 2005; Rahm, 2016).

Ms. Spark's case illustrates that who she is as an individual and as a teacher in her community informs her relationships with multiple stakeholders and eventually shapes how she chooses to conceptualize science learning and teaching in the larger system of her teaching context. Most importantly, all these individual and collective (systemic) experiences and relationships appear to inform and align with her science teaching through her implementation of sensemaking practices. Seeing her in action helped me to understand how she identifies herself and how her science teaching aligns with her effort to support her students in making sense of science. This is a genuine and critical connection because without seeing how a teacher's *self*, values and priorities transform (or do not transform) in classroom settings, we most likely lose sight on how those critical prior experiences and connections interact with each other in a teacher's developmental and transformational process. Without amplifying practice, we are unable to see what negotiations and relationships take place between teachers and students and what modifications and adaptations happen in the curriculum by the teacher to support students. Therefore, this framework signifies how critical it is to provide a holistic and realistic view of teacher identity development by considering and investigating multiple levels of teachers through their personal experiences, conceptions, and practices. This framework can also contribute to teacher education and can act as a tool or roadmap for practitioners to consider identity as a transformational process that is socially constructed, individual, and a systemic interplay between social and institutional forces and realities that take place in teaching context (Calabrese Barton et. al., 2020; Carlone, 2022; Dixon, Harris & Ballard, 2022).

In addition, another major finding from this research was the importance of considering teacher's personal background and positionality, as well as their experiences with other collective and systemic structures (besides the university methods course), such as their current and future relationships with their field placements, school administrations, district leaders, curriculum coordinators, research partners, or their colleagues. As teacher educators, it is our role to raise awareness and make teachers think about how their individual and collective experiences are pivotal in shaping their vision and implementation of science teaching. We should consistently work with PSTs and ISTs to have these critical conversations and reflections on 1) what constitutes their journey of developing teacher identities and how important it is to

embrace this critical work on understanding their positionalities and conceptions of who they are, 2) what they think of what science is and what constitutes science, 3) what role/position they imagine having as a teacher in their classrooms, 4) what type of relationships they aspire to build with multiple stakeholder in teaching communities, 5) in what ways they would work towards to foster critical consciousness in teaching science, and 6) how and why would they adapt or modify their existing curriculum documents to move towards sensemaking and justice-oriented direction in science teaching. With regard to these critical questions, this proposed teacher identity framework can serve as a tool or directory for teachers. It has the potential to encourage teachers to see how the components of the framework work together as parts of a larger system in making sense of their ever-changing teacher identities.

In terms of the research on sensemaking, the study provides evidence to suggest that centering sensemaking practices and amplifying the equity and justice-oriented lens is essential to designing relevant, responsive, and critical science learning environments. In such an effort, a longitudinal design contributes to our understanding of how elementary teachers can develop a sensemaking and justice-oriented mindset, practice, and teacher identity over time. Another critical implication is about the reciprocal and interactive relationship between developing teacher identity and student sensemaking experiences. The major findings of the study show the positive relationships between how the change in teachers' implementation of practices over time also set the foundations for meaningful student engagement and sensemaking experiences in science. Since students also reciprocally engage in and implement the sensemaking practices simultaneously with their teachers, they advance in the experiences of wondering, noticing, identifying, predicting, explaining, critiquing, and eventually making sense of phenomena.

The final point I want to make is how teachers can use *curriculum* as a living document to identify and set expectations for their ideal science learning and teaching environment. Therefore, curriculum becomes a medium for teachers to actively perform the shift in their conceptions and practices of teaching science as they adapt and modify curriculum documents based on their priorities and values, students' needs and contexts. From this perspective, this study contributes to the studies of curriculum development by bringing examples of unexpected and reform-based enactments of teachers as they modify the curriculum to a) support students' equitable sensemaking experiences in science and b) manifest and negotiate their conceptions

(values and priorities) in their science teaching (Berland et al., 2016; Bielaczyc, 2013; McNeill & Krajcik, 2009).

Limitations and Future Directions

As I look back to the time when I started working on this dissertation, I realize once more how all the collaboration and discussions I had with my fellow researchers, colleagues, ML-PBL teachers, PSTs, and, of course, Ms. Spark guided me in creating this dissertation. Even though I engaged with lots of critical ideas and frameworks, raised a number of questions, and used various methodologies during this process, I am still eager to delve more into the questions that I could not have a chance to raise and investigate. Therefore, my future teaching and research will continue to reflect on these critical issues in sensemaking, equity and justice-oriented elementary science teaching, and teacher identity.

In this dissertation, I conducted a single case study to closely and longitudinally delve into a specific context and the experiences of a teacher and her students. Conducting a single case study across multiple years allowed me to: a) represent how Ms. Spark and her students engaged with implementing sensemaking practices across 3 years over 5 year span; b) build more meaningful, open, and honest relationship with Ms. Spark as I keep consistently collaborating and working with her, c) become more familiar with the larger system of her teaching community (her school, professional and community context), and d) observe more closely the changes she went through both in her personal and professional experiences and in her identity development. Such detailed, longitudinal, and in-depth examination would not have occurred if I worked with multiple teachers over a short span of time. The complexity and challenges of the data generation and analysis process used in the single case study would not be possible working with many teachers. Therefore, I argue that conducting a single case study in a longitudinal context has affordances and advantages to explore changing teacher identity within their personal backgrounds, changing practices and their negotiations within the system. Through single case study design, I was also able to a) collect details on Ms. Spark's case that other research designs would not necessarily obtain, and b) combine different data generation and data analysis techniques, and c) generate information and data that was not expected before the study started (Flyvbjerg, 2006).

Although single case studies have affordances, they hold certain drawbacks. Most importantly, this study suggests that sensemaking practices acted as a critical instructional and

pedagogical tool for Ms. Spark as she moved away from traditional way of teaching science and having a behavioral frame to reform-minded way of teaching science and adapting a sensemaking frame. Aligning with her changing practice, I also observed students' sensemaking experiences getting richer over the years as they were exposed to using sensemaking practices earlier in the school year. Many potential explanations and reasons exist for these positive changes as I discuss before (such as Ms. Spark's commitment to change, her fruitful collaboration with the ML-PBL researchers and her approach to the curriculum, her priority of bringing students' family and cultural background to science, and her willingness to work towards equity and justice-oriented perspective). However, we cannot argue that these experiences would be similar or as transformational to other teachers and students. One potential reason is because we don't know their contexts and relationships within the parts of the system, the curriculum they use, and the prior personal experiences.

Therefore, I argue that the proposed identity framework and sensemaking practices in this study are not yet part of a generalized model. But we can assume, based on the characteristics of the case, that these practices, teacher's personal prior experiences, and their negotiations and relationships within the parts of the larger teaching and learning system might be important to capture changing teacher identify over a long period of time and how using sensemaking practices might foster students' sensemaking experiences. Additionally, working with multiple experts to review this case could have strengthen the claims that I proposed in the findings. Therefore, further research becomes critical to address these drawbacks.

In terms of my future research, considering my own positionality and personal curiosity, as well as the limitations of the current study, I have these lingering questions: a) to what extent are the sensemaking practices applicable, relatable, and relevant to different local and global contexts, b) what alternative findings and closing arguments would I reach in relation to student sensemaking and teacher identity, if I conduct such study in a different location and context (considering teachers' individual, collective and practice level experiences would vary in different contexts and realities). Therefore, a larger study using a multiple case study design focusing on rural and urban school contexts can make a substantial contribution to a) grasp the entire ecology of sensemaking in science, b) capture the full complexity of diverse teachers' instructional practices and repertoire, and c) understand the relationship among teacher positionality, conceptions, and practices within various school cultures and contexts.

More specifically, from a local perspective, I gained insights of an experienced White teacher from a rural school district in the Midwest through Ms. Spark's case. Even though her case becomes representative of several other districts in Michigan and other States in the US (in terms of predominantly White teacher and student populations with socioeconomic hardships), I do know that working with teachers and students from culturally and linguistically diverse communities would bring a different perspective and set of experiences to investigate changing teacher identity development and student sensemaking. Therefore, one of my future goals is to conduct participatory design research where we have partnerships and collaborations with teachers and students from diverse communities to address these critical issues.

Moreover, I am interested in studying more ways of pushing the boundaries of normative science education and centering multiple epistemologies and identities in the context of science teaching and learning. To do so, I raise these critical questions for future investigation: a) how would incorporating sensemaking practices in PSTs' teacher preparation program and in-service teachers' professional learning look like? b) in what ways do PSTs and ISTs engage with the multiple ways of knowing and doing in their science classes and develop a more sensemaking and justice-oriented science teaching.

With these future directions, my ultimate goal for researchers and teacher educators would be to recognize and explicitly identify how who we are and our ways of knowing and doing are contextually derived and inform our conceptions and practices of science and teaching in real classroom settings. My future goal is to work with teachers a) to work towards creating more equitable and justice centered learning environments and b) to prioritize sustained critical self-reflection opportunities related to science and teaching as teachers consistently question why we believe and act in the ways we do and work to make connections between individual ways of thinking with larger social, cultural, historical, and political contexts.

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APPENDICES

APPENDIX A. INTERVIEW QUESTIONS

Part 1: Personal Background / Previous Experiences on Learning and Teaching Science

1. I'd like to talk a bit about who you are. How would you identify yourself? What social or cultural markers- for example, race, ethnicity, religion, gender, language- are salient to your identity?

2. I want you to draw a timeline of your life. Through my questions, I hope we can do that.
    a. Where and when you were born and grew up?
    b. Where did you live and study from elementary school to the university years?
    c. Why did you want to become a teacher? What was and is your motivation?
    d. For how many years is you teaching science? Have you taught other subject areas, too? If yes, which ones and for how long?
    e. Where did (at what school) you teach before? For how many years and which grades?
    f. When did you start teaching here in this school? Which grades and subject areas you taught in here?
3. I know your connection and passion for the agriculture and farming that you mentioned me and shared with me before.
    a. I wonder how did that part of your identity connects to your science teacher identity?
    b. In what ways, do you see that relates to your approach to science and science teaching?
    c. How do you think your personal background and experiences would connect/impact your way of teaching science?
    d. How do you think your personal background and experiences would connect/impact your way of teaching science to students with diverse backgrounds and needs? (based on your students' socioeconomical background, race or ethnicity, gender, language, special needs)?
4. Recently, you were also talking about your communication with parents and how important for you to building these relationships with families. Especially I remember when you invite the parents who are into falconry during the Bird Unit. I think it was a meaningful way to bring that home, family, and community connection to school and science. What would be your thoughts on that?
    a. I wonder how do you center family and community connection in your science teaching?
    b. Could you tell me more about that?
5. What's your philosophy of teaching science? What's important to you in teaching science?
    a. What do you value in teaching science?

b. How would you describe the ideal science teaching and learning environment? What is your and students's role in that space?

Part 2: Experiences on teaching science with using ML-PBL curriculum and sensemaking practices & relationships with the parts of the system

1. Can you describe your science teaching experience prior to ML-PBL?
   a. What kind of science teaching and curriculum was it?
   b. What kind of practices you were using? What was different?
   c. When did you start teaching ML-PBL?
   d. How do you think ML-PBL is different than your previous teaching? In which ways?
   e. How did you become aware of ML-PBL? How was your interaction with your administrator and with the curriculum coordinator as you start using this new curriculum?
   f. How was your learning process of the curriculum and these new teaching practices?
   g. What was your experience on being a part of professional learning community?

2. You were working with Sarah as kind of the co-instructor. What was the nature of your collaboration?

3. How about your relationship with your school, your administrators, the curriculum coordinator, like the part of the community/system in your science teaching.

4. Do you think your science teaching has changed over the years? If yes, in what ways do you think your teaching changed? Can you give me some examples?

5. Now let's dive more into your teaching of ML PBL using sensemaking practices. I would like to go through your engagement and use of each of these practices now.
   a. What sensemaking practices do you think help your students to make sense of or figuring out science phenomena?
   b. How do you think those practices serves to that purpose?
   c. Over the four years, how do you think you use driving question and driving question board?
   d. How do you think that your and students' use of modeling and building artifacts and having indoor and outdoor investigations support students' sensemaking?
   e. How do you think that you and your and students use of discourse moves over years?
   f. How does ML-PBL help you to make connections with other subject areas? Especially how does it connect to math, literacy and students writing and reading skills?
   g. In what ways, sensemaking practices and ML-PBL guide you to support students, especially from diverse backgrounds considering the context of your classroom and your school?
   h. How do you think ML-PBL provide guidance to work towards more equitable and justice-oriented science learning environment for all students?

6. Based on what we talked before and after some of the specific focal lessons, especially the tree lesson with equity and SEL goal in the Squirrel Unit or where you read a book about Lonnie

Johnson story or family interviews lesson in Bird Unit... So, I want to talk a little bit about those specific lessons. Could you tell me more about your experiences in teaching those lessons?

7. How do you know if your students make sense of the science ideas? How do you assess their learning?

8. How do you support students to develop science identities that allow them to position themselves as experts and knowers in science learning?

9. How do you feel about your developing changing science teacher identity over the years?

10. In terms of the future orientation for your science teaching, how do you see your future science teaching? Do you plan to change things in your instruction? In what ways?

APPENDIX B. THE ANALYSIS TABLE FROM THE YEAR 1

This shortened table provides a glimpse of how I analyzed and spot critical moments where Ms. Spark and students implemented six core sensemaking practices. For the full version, contact the author.

Table 10. The Analysis from the Year 1 (2018-2019)

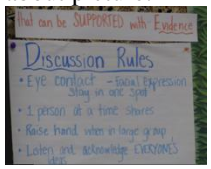
Y1: 2018-2019	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 1 Unit/ Lesson **SQ_LS 4.2**	1. Before introducing the DQ, T give some time to students to reflect back on the timeline. Her questions are more general at this point:  *The last time we got together,* ***we were trying to learn a little bit more about the Stegosaurus*** *and his, um, the environment. And so, we created a timeline.*	The discussion post is not necessarily in the curriculum Prioritizing going through the rules of discussion, setting the discourse norms (that I haven't seen any other classes- see the classroom picture). I can say that it made a difference. Below they are discussing about picture: 	1. Here, before teacher saying anything about what resource or evidence we have, student referred to the article they've read together, which could show Ss understand the importance of presenting evidence to their claims (picture from the class): ***T:*** *Okay, so you think we're going to learn a little bit about, um, maybe some of the plants like?*		Towards the end of the class, T highlights all the conversations, discussions, and videos they watch and guide students to work together to set the timeline of the events. T brings that 4 picture on the ground for students to work with and decide together- it's a pretty good discourse round and T give them a space to freely share/agree and disagree with each other: *T: All right, so thinking about what we learned from our timeline?*		Going constantly back to the previous lesson (building on prior knowledge) Teacher's language/choose of words: ***We were trying to learn more about the Stegosaurus*** Learning about vs. figuring out The way of introducing unit and lesson DQ (not referring back to students' Qs or DQB)

Table 10 (cont'd)

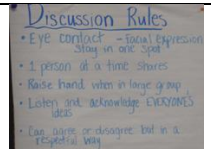
Y1: 2018-2019	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 1 Unit/ Lesson: **SQ_LS 4.2**	*I put it up here so you can kind of see it. So think back to that activity.* ***What did you learn about Stegosaurus?*** *Um, when we did this activity. So turn and talk to your neighbors.* 2. After students turn and talked about timeline, T introduces the DQ. Knowing how she introduces the DQ in the following years, I can see that she is figuring out the lessons, DQ etc.: *Let's look at our big driving question is, why do we see so many squirrels, but we don't see stegosauruses.*	 **T:** Turn and share. Show me that you're ready. Make sure you're crisscross applesauce and your eyes are up here. Riley, what do you notice? **S:** It looks like there's plants. ***T:*** *In that picture. All right, so they look like some type of plant.* ***S:*** *There's some kind of bone on the ground.* ***T:*** *Okay, so she said this thing right here looks like a bunch of bones. Um, Jaren.* ***S:*** *Um, there's something that looks like a carrot right there.*	***S:*** *Because in the article we read, it said they didn't eat like other dinosaurs. But they ate plants.* ***S:*** *Okay. We might learn a little bit about the plants and maybe what the maybe what they ate.* 2. Teacher shows the pictures from different time periods reflective of the timeline. Her colleague also takes an active role in capturing students' ideas and building on classroom consensus (knowledge building process)		*recent today and then thinking about our video that we watched. Do you remember the one with the Stegosaurus and the little creature? Remember that. Thinking about that,* ***we're going to try to put these in order from what we think is most longest ago to the most recent. So, stand up and form a circle.***  ***S:*** *All right, so looking at the different time periods, post posters or pictures, which one do you think would be the most longest ago? Which one do you think would be the*		Level of depth in navigating discourse (beginning low and becomes moderate) Going through Discussion Rules Collaboration with the other teacher (Sarah) Active group work through the timeline and pictures (beautifully going through each of them as students raise their noticings, at the end they have a class consensus chart-ish)

Table 10 (cont'd)

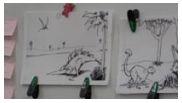
Y1: 2018-2019	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 1 Unit/ Lesson **SQ_LS 4.2**	*We want to try to answer that second part, because we've talked about squirrels and their structures and how that helps them to survive with other in their environment, with other organisms. So today we're going to talk about what were the past environments like. So now we're going to focus on the Stegosaurus and we're going to work backwards. So how did the Stegosaurus survive in his environment. What structures did he have. **What do you think we're going to talk about with our, um, learning our, uh, lesson question today?***	***T:** Okay, let's get a little bit like a shape, like a carrot. Anybody want to add to what he said about that creature there, Claire?* ***S:** It looks like a unicorn.* *T: Um, boys and girls**, I want to remind you our discussion rules is one person at a time**. Our rules are right up there. So, turn and look up there so I can remind you. When someone is sharing you make sure that you use eye contact and that you're sitting still. Only one person at a time shares. You raise your hand when you want to share something,*	using these images (see the picture). T also capitalizes the word ***noticing*** which guide students to express their own observations and ideas (making them prepare for notice and wonder charts)    *T: I have some pictures of different time periods*		*longest ago? Brody?* *S: The first one.* *T: What do you think? Why?* *S: Because it's a dinosaur.* *T: Okay, so he says he thinks that this one was the one that happened most longest ago. Because he says it has a dinosaur in it. All right. Anybody want to add to what he said, or do they want to come up with their own idea?* *S: Um, I disagree with Brady because, um.* ***S:** Because we kind of know a lot about dinosaurs now. So if you since it's now we're learning about it, but, um, we like don't see those and see that often.*		Students work in circle and try to figure out the timeline of each creature was born and lived, T never leads or impacts students thinking, basically revoices their claims and affirms that students can come up with different claims After putting the pictures in order, teacher introduces students with number of articles so they can bring evidence to their claims and rework and finalize

Table 10 (cont'd)

Y1: 2018-2019	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 1 Unit/ Lesson: **SQ_LS 4.2**	*What were past environments like turn and talk to your neighbors. Well,* ***what do you think we're going to talk about your question.***	*So. raise your hand and add on to what Jaren said in a respectful way.* ***S:*** *Looks kind of fiction, because I don't think it's true that carrots can be like.* ***S:*** *Um, would you think it looks like I think it.* ***S:*** *I think it still, I think it just looks like a plant with, like a dead plant.* ***T:*** *Okay. So she says it kind of looks. Reminds her of a little bit of, like, a plant. Brody, what do you think?* *Student: Squid!* *T: Okay. Kind of like a squid like creature. John?* ***S:*** *Along with what he said because it kind of looks like a squid.*	*during that fit in our timeline. So, I'm going to show you the different pictures. I want you to think about what you notice in them. So, this is the first one. Turn and talk to your neighbors about what you notice.* **S:** I noticed that it um, it like bends over to touch the ground, I guess. like the dinosaur. Like tips it and it makes its tail go up. **S:** I notice there's a lot of palm trees. **T:** Okay, so what does that tell you about what it would be like there?		***T:*** *All right. She thinks this is the one that's the longest to go because these are, um, organisms that we probably wouldn't have seen today or the most recent. All right. Anybody want to add on to what they said. Jaren, what do you think?* ***S:*** *I think that fishy thing goes right there.* ***T:*** *Okay. Why? Um.* ***S:*** *Because that looks like a cat and that looks like a rhino.* ***T:*** *Okay, so why do you think that would be the most recent, then?* *S: Um. Because it's A Komodo dragon*		their timelines Connecting the info in the articles as a type of evidence to support claims in determining timeline

APPENDIX C. THE ANALYSIS TABLE FROM THE YEAR 2

This shortened table provides a glimpse of how I analyzed and spot critical moments where Ms. Spark and students implemented six core sensemaking practices. For the full version, contact the author.

Table 11. The Analysis from the Year 2 (2021-2022)

Y2: 2021-2022	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 4 Unit/Lesson: **ToyLS 1.1**	Brief reminder of the previous lesson, introduction of the unit DQ; not much discourse around the DQ itself though T: Just as a reminder, our driving question for our unit is how can we design fun, moving toys that other kids can build? And we started to share some family stories about maybe some parents, maybe some grandparents that maybe made some toys or had some toys that	Teacher let students to figure out the goal and reasoning of the investigation they are gonna do. She uses discourse prompts to support students to come up with the connection of how the investigation would help to figure out the DQ (why they do that, what their goal there is, why their predictions are essential part of sensemaking!): T: And then if somebody is launching it what are you doing, what are you going to be?	After T went through the DQB, she transitions into explaining the investigation of the day. T introduces all 3 types of rockets that SS will explore: T: **We want to figure out is there a pattern to all of the toys that we use**. Or are there some things that make them different. And then maybe some questions that we might wonder about so that maybe we can that will	Teacher spends time to make sure defining some of the main terminologies and points of discussion. There was a good discourse as students coming to a consensus on what system and pattern of motion means. T: We started to talk about this one right here. **This is a system. What do I mean by system?** S: System to make the rocket go.	After talking about DQ, system and pattern of motion, T invites a student to stomp a rocket so students can see the pattern of motion of the rocket: T: Let's have somebody launch the air rocket and we'll see what it does this time. All right. Grayson. Do you want to try it? We're going to watch to see what happens when he stomps it. All right. Let's do it one more time and let's see what we notice about maybe the		The way of introducing unit and lesson DQ (not referring back to students' questions or DQB in the beginning). However, T points out to the previous lesson to build things together. The wording changes into **figure out, explore, explain...** **Language related to CCC (Not just DCI)-this is valuable-influence of teaching materials-3d learning**

Table 11 (cont'd)

Y2: 2021-2022	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 4 Unit/Lesson: **ToyL S1.1**	moved in different ways. So that might help us when we're trying to design a toy that other kids can build. We played around with this racket last right before break. I'm going to get this one out right here. We started to talk about this one right here. Remember this? We talked about that. This is a system. What do I mean by system. After Grayson stomped the rocket and Ss had a discussion, T went back to Ss previous Qs from the wonder board and make sure to	**S:** standing back and watching. **T: what are you trying to look for when you're watching it? What are you trying to figure out**? When you're watching somebody launch the rocket, what do you think you're trying to notice? Avery. S: A different or the same way they go and how it goes. **T:** The ways that it moves the same, maybe the ways that it moves different, right? Is that what you're talking about? Anybody **wants to add to what she's saying**. What else are you going to look for? Maddie. S: Pattern.	Help us to design a toy for another kid. We got these rockets right here. She shows the worksheet that they need to fill as they investigate (notice and wonder chart). She also assigns roles to make sure everyone is involved and its fair: T: You're going to **explore three rockets today. One is the one we already explored this. That one's the large one.** This one's going to be the medium one.	**T:** Yeah. System to make the rocket go. what are the parts of the system that make the rocket go? S: the palm. S: The tube. K: The tube that runs from here to the pump there. Miles? S: The stand that holds the rocket. T: Tessa? S: The rocket, the rocket itself and the air that goes into it. **T:** Okay. All right. Anybody else? All right. You guys agree with that? Okay. The system has parts to it to make the rocket move and to work. We were also trying to when we launched it,	pattern, the thing that, um, the cycle or what happens over and over again.  **S:** Whoa. **T:** What did you notice? What are some things that you noticed? Why don't you turn and talk to your neighbors about things that you noticed about the rocket? **Meaningful responses below:** S: It was fast both times. T: it was fast both times so was the speed of it or was it launched really fast both times? What else?		Teacher puts a good focus on defining some of the main terminologies and points of discussion. She facilitates a meaningful discourse as students define what **system** and **pattern of motion** means. T help students to come up with definitions by collecting students' ideas. In doing that she revoices S ideas, ask follow-ups and called out students' names to make sure to give them ownership. She uses turn and talks number of times to leverage whole group conversation.

Table 11 (cont'd)

Y2: 2021-2022	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 4 Unit/Lesson: **ToyL S1.1**	through them to address some of them and to add new ones: **T: Okay. We asked some questions last time. I posted all our questions on the wonder board back there.** We had some questions. Let me just turn your bodies a little bit. And I'll just read a few of those questions that we had. Um, and maybe you're thinking of some more questions that you're wondering about right now. T: We kind of grouped them up to ones that were about the structure of it.	T: Patterns of what? S: Patterns of how it looks the same or it doesn't when we launch. T: Sure. Patterns of how it moves. Like maybe. How far does it go? How fast does it go? The speed of it. Maybe distance like the distance of it. So just like we looked at the pattern of this one, we noticed that each time it goes straight up wiggles, and then and then it comes right back down and bounces off the ground. You're looking for those things. What are the things you notice about how it moves. All right.	then this one's going to be the small one. Yep. All right. Turn your body so you can see the screen because you're going to take notes as you observe today. All right. This is going to be your, um, paper to take some notes as you are. Your team is launching the different rockets. You'll see rocket one I put large there so you can remember that that's rocket one. And then I put next to rocket two I put medium so that you knew it was this one.	we were trying to notice some things about how the rocket moved, and we were **trying to figure out** a pattern of motion. I wrote that up there, a pattern. **what does that mean, a pattern of motion**. How about you **turn and talk** to your neighbors about what you think the pattern of motion might be? **T:** turn and share. What did you guys talk about? What do you think the pattern of motion is? **S:** Maybe it like. It is like the pattern of motion keeps.	Hayden, what did you notice? **S:** Like went up really fast and then it just like, moved around and came back down. **T:** All right. So each time it went up really fast, wiggled around and then came back down. S: Wiggle around. That was going back down okay. T: While it was coming back down. All right. Tessa. **S:** On the first time that he launched it, it wasn't all the way down to the rims and it didn't go quite as powerful. But the second time, when it was down farther. …		After talking about DQ, system and pattern of motion, T invites a student to stomp a rocket, so students can see the pattern of motion of the rocket in action. As she does that students were able to observe the phenomena first-hand multiple times and share their noticing and prediction by building on each other's ideas. **(Form of scaffolding- teacher modeling of instruction- Y1 to Y2)** DQB helped T to transition to the new investigation that students will conduct on different types of rockets and their

Table 11 (cont'd)

Y2: 2021-2022	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collaboration)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 4 Unit/Lesson: **ToyL S1.1**	Some of them were I wonder if the wings on the bottom, um, helped it go so high. We talked about the wings on the, on the rocket itself. Somebody asked, does the point make it go farther? Um, why does somebody ask? Why does it have a tip? Um, and then if there was a hole in the tube, what would happen to the rocket? Would it change the way it moves? And then we had some about distance and speed, the motion of it. Some of them were what direction would it go with and if it was windy…	Very end of the lesson where there is a whole class discussion based on students' noticing and wonderings and shows how students construct the knowledge together and T was collecting students' ideas and acted like a moderator: T: Okay, we got like five minutes, and I want to just kind of wrap up with some things that we noticed, maybe that were different about the ways that the rockets moved, maybe some things that made them similar to each other. Let's just look at your notes. Emma? …	This is the rocket two. And then rocket three is the tiny one. The small one. That's this one right here. All right. So as your team is taking turns launching it so each person can launch at once, let's just say **that's that would be the fair thing to do.** And then if somebody is launching it what are you doing, what are you going to be?	T: Okay, so something that keeps it moving. All right. What else? Maddie? Um. **S:** Even though the rocket doesn't always shoot up the exact same, it's the same. It's going through the same cycle to make this rocket go T: Okay. Did you guys hear that? She said even though it might not move exactly the same each time, she's saying it's kind of like a cycle. It does this a similar thing each time. Okay. Anybody want to add to what she said, Amirah? …	Final part of the lesson: Students work in their small groups to conduct their investigation; working on three different sized rockets to figure out their pattern of motions: One of the group's work and convo as they worked with the middle-sized rocket:  S1: I know that it pointed really straight up. Going straight and shake it on this. You see that one? S2: Let's talk about we're going to write our questions…		patterns of motion. In that way, this is one of the top lessons that includes many SMP interwoven in a deeper way. Teacher let students to figure out the goal and reasoning of the investigation they are gonna do. She uses discourse prompts to support students to come up with the connection of how the investigation would help to figure out the DQ (why they do that, what their goal there is , why their predictions are essential part of sensemaking!) …

APPENDIX D. THE ANALYSIS TABLE FROM THE YEAR 3

This shortened table provides a glimpse of how I analyzed and spot critical moments where Ms. Spark and students implemented six core sensemaking practices. For the full version, contact the author.

Table 12. The Analysis from the Year 3 (2022-2023)

Y3: 2022-2023	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collab.)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 5 Unit/ Lesson **SQ_L S5.6**	T lets students know that they're going to read a story which connects back to their DQ and what they have figured out in the previous lesson. **T: We don't really read stories too often, but this one's a really good one.** I think you'll like it. And it will help us to answer this question that we have up here. It says, where have scientists and other citizens found fossils from the Jurassic period.		She introduces the book and the character in the book. She uses the globe to show where the story takes place and shows how far is England from Michigan.   T: I'll show you on the globe where it where it's where she's at. We're right here. Here's Michigan, the United States.	T makes sure to navigate really interactive read-aloud discourse where she pauses many times in between the reading, showing the images from book; going through the meanings of certain notions with students, and most importantly asking lots of questions that where students can also bring their own personal experiences: **S:** Because all those dinosaurs look like it's like a bunch of rhinos. And most of them kind of look like		T support students in bringing their own personal and family experiences on science phenomena (such as fossils) and what they have figured out in science lessons. In that way, T perfectly brings the literacy connection to the science and connect back the content of the book to their science phenomena. She also makes sure to ask about what experiences, characteristics and feeling that the character has and might been go through as a young kid and help	T lets students know that they're going to read a story which connects back to their DQ and what they have figured out in the previous lesson. This also shows that T doesn't necessarily goes through these read aloud SEL goal lessons, she included/taught this lesson as I visit her class. She introduces the book and the character in the book.

Table 12 (cont'd)

Y3: 2022-2023	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collab.)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 5 Unit/ Lesson **SQ_L S5.6**	You were thinking of a movie? Apparently Jurassic Park. We've been talking about why we see so many squirrels, but we don't see stegosauruses. **T:** We figured out that, um, it that if we find a fossil that will help us to gather evidence about what it was like back then during the Jurassic period, and then what other organisms will live there and maybe what happened to them over time. This is a story. It's called **Stone girl, Bone Girl.**		Over here across the ocean right here is where Mary Anning lived and grew up. So right over here. So here we are. Here she is over here. S: It's like one ocean away. Oh, one ocean away. S: So Atlantic? T: Yep. Cross the Atlantic Ocean. So that kind of gives you a little bit of an idea of where she's from. So this if you look at this cover here, I'll kind of open it up because it's kind of a picture goes across the two pages. **What do you notice about the cover? What do you think this book is going to be about?** **S:** I think it's about, um, how she finds fossil in her homeland.	they're in the dark. **S:** Um, it's like about dinosaurs and fossils. T: Okay. Dinosaurs and fossils. What do you think, Stone girl? Bone girl is going to mean? Stone girl, bone girl. Lincoln? **S:** She might find, um, like bones or fossils from the dinosaurs. **S:** and stone. T: Okay. All right. When Mary Anning was a baby, she was struck by lightning. I know it's kind of crazy, isn't it? **S:** How is she not dead? T: Sometimes people can survive. And she did it. Was it split a huge elm tree and threw Mary right out of her nurse's arms.		empathize with the character as a young kid, explorer, and scientist. T: Okay. Dinosaurs and fossils. What do you think, Stone girl? Bone girl is going to mean. Stone girl, bone girl. Lincoln?  T: I wanted you to think about. In that picture there you can see the cliffs and then the sea and all the rocks and stuff by the sea. So that can kind of give you a good visual in the head. Why, he she held on to her dad's hands so carefully. T: The clay cliffs at Lyme Regis are soft as melting chocolate.	She uses the globe to show where the story takes place and shows how far is England from Michigan. T makes sure to navigate really interactive read-aloud discourse where she pauses many times in between the reading, showing the images from book; going through the meanings of certain notions with students, and most importantly asking lots of questions that where students can also bring their own personal experiences. She also uses a video at the end that similarly covers the story of Mary Anning and her contributions to the science.

Table 12 (cont'd)

Y3: 2022-2023	**SMP1 (DQ)**	**SMP2 (Discourse)**	**SMP3 (Multimodal)**	**SMP4 (Multiple literacy)**	**SMP5 (Collab.)**	**SMP6 (Working Towards Equity and Justice)**	**Takeaways from each class**
Class 5 Unit/ Lesson **SQ_L S5.6**	T: It's a story about a girl named Mary Anning, and she's from, it's called Lyme Regis. I put a picture up on the screen so you could kind of see what it looks like.		**T:** Okay. And why do you say that? **S:** Because all those dinosaurs look like it's like a bunch of rhinos. And most of them kind of look like they're in the dark. 	Her father was in his carpenter's shop when he heard the terrible news. He dropped his hammer and ran through the stormy streets of Lyme Regis. Gently, he lifted the limp body of his little daughter, and his tears flowed like rain. But then an extraordinary thing happened. Mary Anning slowly opened her eyes. She reached out a tiny hand and touched the amazing face of her father, and the little girl began to smile. It was then that her father realized that Mary Anning was going to be no ordinary girl. It's pretty extraordinary, isn't it? …		Mary had sometimes seen huge slabs of land slipping and tumbling into the beach below. **T: How many of you been up in the U.P. and you've gone to the pictured rocks?** S: Me and my mom have! **T:** You can **probably connect to that**, because sometimes what happens on the pictured rocks next to the lake. What happens to them? S: some of the rocks might fall T: They don't let you get real super close to the cliffs because they don't want you to fall off of it. …	T support students in bringing their own personal and family experiences on science phenomena (such as fossils) and what they have figured out in science lessons. In that way, T perfectly brings the literacy connection to the science and connect back the content of the book to their science phenomena. She also makes sure to ask about what experiences, characteristics and feeling that the character has and might been go through as a young kid and help student to empathize with the character as a young kid, explorer, and scientist.

APPENDIX E. FINAL SUMMARY ANALYSIS TABLE

This shortened table provides a glimpse of how I summarized and recognized critical moments/arguments where Ms. Spark and students implemented the six core sensemaking practices in the 3 years across the 5-year span. For the full version, contact author.

Table 13. Summary Analysis to Illustrate the Core Changes in the Implementation Across the Years

Year 1 (2018-2019)	**The core changes (changing patterns) in the implementation from the beginning to the end of each year**
SMP1 (Driving Question)	- Dynamic start but inconsistent focus on connecting back to previous lessons (through the discussions and investigations) and students' prior knowledge and experiences - T's consistent choice of wording during the year as she facilitates the discussion around the DQ and sets the learning goal of the lesson: "trying to **be learning about**…" and "trying to **answer the question**…". - Inconsistencies in introducing both Unit and lesson DQ during the lesson and visible integration and use of DQB
SMP2 (Discourse Moves)	- Setting the norms for a meaningful and respectful discussion and discourse environment (not so detailed but a nice start) - From using some of the discourse moves to using variety of them a) to make students' ideas visible and promote quality discussion about DQ and Qs from the DQB, B) to highlight and connect students' prior knowledge and experiences from their indoor and outdoor investigations, and c) to support students as they form claims and use evidence.
SMP3 (Multimodal Representations)	- Students start working with different multiple representations, such as articles, images, websites, and videos from to experience phenomena second-hand about different prehistoric eras, characteristics of variety of birds, - Students started to create multimodal representations, such as artifacts, consensus, and individual models, wonder and what I know boards, notice, and wonder charts etc.
SMP4 (Integrating) multiple literacies)	- There wasn't much of math or literacy integration to the lessons to promote multiple literacies of the students - T makes sure to facilitate discussion when students encounter a new concept or term that they might not be familiar with. Through the discourse, students come up with definitions of the concepts drawing from their experiences.
SMP5 (Collaboration)	- Whole group discussions and small group work (indoor and outdoor investigations) constitutes the collaboration - Collaboration started to become a SMP that involves other SMPs as T and Ss conduct and share their investigations through using discourse, multimodal representations, and reflecting back on the DQ and DQB. - T started to develop a mindset and underlined constantly the importance of using evidence to support claims as students come up with their predictions and explanations - Investigations and artifact building started to become an important venue for students to experience and explain phenomena as they keep working on their C-E-R experiences to make sense of the phenomena
SMP6 (Working Towards Equity and Justice)	- Lack of critical connection to equity and justice. One of the lessons has an SEL goal of developing interest which was superficially connected back to students lives and interest. - T was enthusiastic about bringing her life experiences and family connections to the class, allowing students to know more about her, and start to build more meaningful relationships. It also encouraged Ss to bring their family experiences related to phenomena.

Table 13 (cont'd)

Year 2 (2021-2022)	The core changes (changing patterns) in the implementation from the beginning to the end of each year
SMP1 (Driving Question)	- Consistent connection back to the previous lessons and investigations before starting a new DQ, so that Ss can construct the knowledge together using prior experiences to current experiences - T's choice of wording started to shift from Y1 as she facilitates the discussion around the DQ, and sets the learning goal of the lesson: "trying to figuring out…", "trying to explore", "trying to explain..." - Consistency in introducing Unit and Lesson DQ during the lesson; however, T lets students read and introduce the DQ: "you will teach others…", "you will research…" - Meaningful integration of Qs from DQB to the phenomena and investigations; but inconsistencies in using the DQB - T was much more vocal and nuanced on why they do the investigation and how what they do support/connect to their process of figuring out the phenomena/DQ.
SMP2 (Discourse Moves)	- Variety and quality of using discourse prompts (also how/why follow-ups) increased - In-depth discourse about the DQ by bringing students' previous experiences and investigations - T's ability of collecting students' ideas and represent them as new knowledge- even when students didn't express their ideas explicitly, she was able to pick them up and rephrase in a way that make sense and further the discourse - The facilitators of the discourse also shifted to parents: Ted and Nina used various discourse moves smoothly to connect students' experiences and observations while making predictions and bringing explanations about birds.
SMP3 (Multimodal Representations)	- Using and creating multiple representations greatly impacts and supports students' experiences in a) collaborating with the peers, b) finding different ways to represent, explain and make sense of science phenomena, c) building claims using evidence with reason, d) co-constructing knowledge - Starting at the end of the Squirrel Unit, equitable modes of modeling and representation increased. T started to prioritize what type of representations would be meaningful, relevant, and helpful for students to connect back to their previous experiences and present and explain phenomena in various ways such as through narratives, sketches, skits, drama etc. - Consensus models become a main tool especially during the Toy Unit for T and Ss to figure out how they can build individual models, to enrich the discourse by unpacking concepts. - Multiple representations become a tool to connect first and second-hand experiences for students as they experience phenomena (such as using their outdoor experiences of *Sit Spots* and *Wonder Walks* in Bird Unit to confirm/identify the local birds they see through Allaboutbirds.org)
SMP4 (Integrating) multiple literacies)	- T supports students in explaining central concepts (such as fair test, system, and patterns) by collecting students' ideas, drawn from their observations and everyday experiences. In doing so, T moved away from just unpacking concepts related to DCI with students, but also addressing the CCC. - Ss actively worked on investigations that promote and incorporate Math Literacy. Ss worked on identifying variables within fair test, using different unit of analysis, and measuring distances of motion on different surfaces.

Table 13 (cont'd)

Year 2 (2021-2022)	**The core changes (changing patterns) in the implementation from the beginning to the end of each year**
SMP5 (Collaboration)	- The interconnection and coherence among SMPs become more visible, especially among DQ, Discourse, MMR, and Collaboration through investigations - The collaboration in small group work (investigation) becomes a stronger component as students build, design, redesign solutions and present/act out their artifacts/models. - Small and whole group work become the main source of where students experience and predict how phenomena occur, collect evidence (that teacher constantly highlights), and explain phenomena during the process of figuring out the DQ.
SMP6 (Working Towards Equity and Justice)	- T works through students' struggles in writing and reading and works with students who prefers to use different modes of modeling through sketches, narrations, act outs etc., which becomes alternative and equitable modes of exploring, expressing, and explaining phenomena - T more explicitly start bringing family stories and family connections to the science phenomena - T's willingness to build relationships and communicate with parents stands out! She prioritizes bringing family and community connection and interest to the science classroom by inviting parents who are practicing falconry to support students' sensemaking experiences about local birds.
Year 3 (2022-2023)	**The core changes (changing patterns) in the implementation from the beginning to the end of each year**
SMP1 (Driving Question)	- The depth and quality of the discussion around the DQ peaks within and across this year. T and Ss masterfully connect each lesson DQ and goal of the investigations together to figure out phenomena using variety of discourse prompts. - T and Ss connect back to the prior lessons and investigations in each unit, however, students are the ones who bring all the knowledge together by connecting previous experiences to the new DQs through T's facilitation. - The intersection and coherency among multiple SMP are at its peak in each lesson during this year. - T prioritizes and focuses more on asking critical questions to make students think about the issues of equity, fairness, environmental justice, and who gets to become a part of science in society peaks in this year starting from SQ unit.
SMP2 (Discourse Moves)	- Since Y1, this is the first time that T goes through the norms of quality discourse. Unlike Y1, T unpacks different discourse moves to use express, building on, and explain ideas. As students set a baseline of what moves to use, the quality of discourse gets much better and higher level throughout the lesson starting from SQ unit. - T advances in gathering students' ideas and questions to summarize, synthesize and then finally revoice them as the collective knowledge that students co-construct throughout the lesson. - As Ss excel in using variety of moves to clarify and explain their thinking, they also start connecting their everyday experiences to science as evidence to support their claim without further T support. - The use of discourse moves peaks this year as students contextualize them to a) bring their family stories and cultural resources, b) connecting with 1st graders together through the interviews they conduct to redesign their toys, c) raise awareness on the social, economic, and environmental contexts and differences of various communities.

Table 13 (cont'd)

Year 3 (2022-2023)	**The core changes (changing patterns) in the implementation from the beginning to the end of each year**
SMP3 (Multimodal Representations)	- Read aloud of the articles and books becomes the critical MMR tool in Y3 in terms of incorporating science to literacy and leveraging students' critical consciousness of the cultures and needs of different local and global communities. - Consensus and individual models, as well as end of unit artifacts become the core representations that students build together. T masterfully oriented students to use their representations to show how they notice, predict, compare, and explain the overarching phenomena as a part of their sensemaking in each unit. - Unlike in Y1 and Y2, T created sort of a buffet that includes at least 20 different materials that students can use to redesign and investigate their toys. This big range of materials were made of all accessible, everyday materials that students can use and test their ideas based on their imagination and curiosity.
SMP4 (Integrating multiple literacies)	- Besides incorporating Math Literacy (especially within Toy Unit), Y3 becomes the year that T and Ss actively use children's books and number of articles to facilitate read aloud experiences that merges science and literacy components together especially in Squirrel and Toy Units. - T masterfully navigates an interactive read-aloud discourse where she pauses many times in between the readings, shows the images from books or articles, goes through the meanings of certain notions with students, and most importantly asks lots of critical questions where students can bring their personal experiences, interests, and ideas. - T visibly guide students to see the connection between the texts they read and investigations they conduct. For example, as Lonnie Johnson was students were connecting how Lonnie Johnson redesigned his prototypes multiple times to test and improve his Super Soaker and how he showed the designs to the kids to see if they like it or if it works for them. This reminds students that they also designed and redesigned their toys and even show their designs to the 1st graders to get their feedback to strengthen their designs. Connecting the books and the experiences of scientists to students' experiences on learning science was masterful.
SMP5 (Collaboration)	
SMP6 (Working Towards Equity and Justice)	- Y3 was an exemplary year of using children's books to introduce students with community of scientists, inventors, engineers, and researchers from diverse backgrounds. For example, in Squirrel Unit, "*Stone Girl Bone Girl: The Story of Mary Anning*" guided students to figure out how Mary Anning discovered new fossils as a woman in the field of science and how her observations changed the natural science and history world. - The article of "*Trees Grow on Money*" made students realize, question and critique on a) how richer areas in the US cities have more trees and green areas, and what are the potential reasons behind those environmental inequities especially for communities with less resources, b) the ways to raise consciousness to the issues of environmental injustices and act towards equitable planting goals. - These critical texts and discourse in Squirrel Unit helped students to delve into the notions of what equity and fairness might mean in the context of science and society.

Table 13 (cont'd)

Year 3 (2022-2023)	**The core changes (changing patterns) in the implementation from the beginning to the end of each year**
SMP6 (Working Towards Equity and Justice)	- In Toy Unit, reading "*Whoosh!: Lonnie Johnson's Super Stream of Inventions*" made students critically think about how love of inventing things was present in Lonnie Johnson's early life and how his passion for problem solving became the cornerstone of his career as a one of the lead African American engineers and scientists at NASA. Lonnie Johnson story guided students to discuss and critically reflect on a) how important to have an ongoing interest and resilience as a scientists to keep designing and investigating until make sense of and resolve the problems, b) how scientists have the endless curiosity and care as they building and designs inventions for other kids, and c) the historical, social, and cultural challenges that scientists from underserved communities face along the way of working to accomplish their goals. As they had these critical conversations, students were vocal about how they relate to Lonnie Johnson's story and could see him as a role model as they also design toys for other kids and aim to become successful like him. - Centering students' resources and promoting student-lead expertise peaked when students conducted peer interviews with 1st graders in Toy Unit, as well as when they shared family interviews in Bird Unit. Interviewing with 1st graders as they introduce their toys and get feedback on the design changes, helped students to develop critical skills of socio-emotionally connect and collaborate with their peers. - In addition, conducting family interviews were essential to bridge family's historical and cultural stories, experiences, and resources to science phenomena, and to connect those different ways of knowing, and understanding the world around them. --- - Students get to learn more about how different birds can carry different special and emotional meanings for some families and cultures. As hearing students' stories, teacher also opened up about her own family and personal roots and special connection to the certain birds and its reasons.