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A Study of How Middle School Science Teachers Draw on Student Funds of Knowledge to Engage Epistemic Agency

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A Study of How Middle School Science Teachers Draw on Student Funds of Knowledge to Engage Epistemic Agency

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in Education

by

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ABSTRACT

A Study of How Middle School Science Teachers Draw on Student Funds of Knowledge to Engage Epistemic Agency

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Meghan Macias

With school populations across the country becoming increasingly representative of students from diverse cultural and linguistic backgrounds, new considerations must be made to promote equitable and engaged science learning for all students (National Academy of Science, National Academy of Engineering, & Institute of Medicine [NAEEM], 2011). The Next Generation Science Standards (NGSS) respond to a need for equity by explicitly calling on science teachers to "acquire effective strategies to include all students regardless of racial, ethnic, cultural, linguistic, socioeconomic, and gender backgrounds" (NGSS Lead States, 2013, Appendix D, p. 38). Some prior research has criticized the NGSS for simply being another set of standards that constrain what it means to know and do the discipline, and thus, do not allow for diverse ways of knowing that do not align with the standards (Rodriguez, 2013; Miller et al., 2018). As such, there needs to be greater understanding about what effective strategies teachers use to teach diverse learners within the context of a reform-oriented science education landscape that calls for actively engaging students in science practices (Ko & Krist, 2019). The overarching goal of this dissertation is to examine one such strategy, specifically how middle school science teachers in California provide opportunities for epistemic agency by drawing on students' funds of knowledge.

Epistemic agency is a construct which helps us to understand inequity in science education (Carlone et al., 2015). By attending to who has more or less power to direct the intellectual work of the classroom, we come to see patterns in who is afforded more or less power. One approach to attending to issues of power in the classroom and respecting children, their intelligence, and the communities they come from is to utilize a funds of knowledge perspective (Moll et al., 1992). A funds of knowledge approach to teaching and learning encourages teachers to draw on the cultural and community knowledges that students bring from outside of the classroom (e.g., home and family) to counteract deficit perspectives of diverse student populations.

This mixed-methods study seeks to understand how teachers both draw on students' funds of knowledge and enact their epistemic agency in the context of NGSS-aligned instruction. Participants included grades 6-8 science teachers across California, some who participated in targeted, extensive professional learning about the NGSS and some who received little training. The study was conducted in Fall 2018 through the end of Spring 2020. Data were collected and analyzed using qualitative and quantitative methods that included teacher and student survey data, classroom observations, and teacher interviews. Overall, there were increases in teachers' reported average implementation for epistemic agency and funds of knowledge across study years. However, while teachers reported increased enactment of epistemic agency over study years, students reported that the source of the questions and investigations in their class was more often derived from a source external to them (like a textbook, worksheet, or other material that was given by the teacher)

rather than being derived from the students themselves or from their communities. Findings reinforce prior literature that question the NGSS as a set of standards that suggests students be the “do-ers” of science, so long as they are doing the science that is outlined in the standards (Berland et al., 2019; Lowell et al., 2020; Miller et al., 2018). Students’ ideas and questions were not frequently the basis of investigations in class and enactment of epistemic agency only went so far as eliciting student ideas that are recognizably aligned to the standards.

TABLE OF CONTENTS

I. Introduction

With school populations across the country becoming increasingly representative of students from diverse cultural and linguistic backgrounds, new considerations must be made to promote equitable and engaged science learning for all students (National Academy of Science, National Academy of Engineering, & Institute of Medicine [NAEEM], 2011). This includes students who historically have had limited opportunities to achieve in science learning, namely students of color, multilingual learners, and students from low-income backgrounds (National Research Council [NRC], 2012). The Next Generation Science Standards (NGSS) respond to this call for equity by explicitly calling on science teachers to "acquire effective strategies to include all students regardless of racial, ethnic, cultural, linguistic, socioeconomic, and gender backgrounds" (NGSS Lead States, 2013, Appendix D, p. 38). Some prior research has criticized the NGSS for simply being another set of standards that constrain what it means to know and do the discipline, and thus, do not allow for diverse ways of knowing that do not align with the standards (Rodriguez, 2013; Miller et al., 2018). As such, there needs to be greater understanding about what effective strategies teachers use to teach diverse learners within the context of a reform-oriented, standards-based science education landscape that calls for actively engaging students in science practices (Ko & Krist, 2019).

The overarching goal of this dissertation is to examine how middle school science teachers in California provide opportunities for epistemic agency by drawing on students' funds of knowledge. Epistemic agency is defined as "the process that sustains the creation and improvement of ideas via collective contributions in which students take cognitive responsibility for their learning" (Damsa et al., 2010). It is important for science teachers to consider because of its implications for engaging students in a process of sensemaking, a call put forth by recent science education reforms like the NGSS. There have been put forth four main reasons why teachers should attend to student epistemic agency in their instruction. First, for students to see science as relevant to their lives and for students to see themselves as scientists, they need to be invited to engage in the process of scientific sensemaking (Farris et al., 2019). By allowing students to see themselves as epistemic agents in the classroom, they come to see themselves as scientists or science people (Carlone et al., 2015). Second, Zivic et al. (2018) argued that epistemic agency is a construct of importance in science education because it helps with coherence from the student perspective. If a student can identify what they know and how they can go about finding out the answers to questions or solutions to problems, they are able to view science as a discipline with a coherent set of practices rather than a set of facts to be learned. Third, epistemic agency is a construct which helps us to understand inequity in science education (Carlone et al., 2015). By attending to who has more or less power to direct the intellectual work of the classroom, we come to see patterns in who is afforded more or less power. Fourth, agency is a way of respecting children and their intelligence (Louie, 2020). Engaging all students as agentive and powerful actors in the classroom means treating students as capable of leading their own learning with support and collaboration from their teachers and their peers.

One approach to attending to issues of power in the classroom and respecting children, their intelligence, and the communities they come from is to utilize a funds of knowledge perspective (Moll et al., 1992). A funds of knowledge approach to teaching and learning encourages teachers to draw on the cultural and community knowledges that students bring from outside of the classroom (e.g., home and family) to counteract deficit perspectives of diverse student populations. The proposed study expands on previous studies on epistemic agency (Gonzalez-Howard & McNeill, 2020; Sezen-Berrie et al., 2020) by paying special attention to how science teachers draw on funds of knowledge to develop students' epistemic agency.

As such, this dissertation seeks to understand how teachers both draw on students' funds of knowledge and enact their epistemic agency in the context of NGSS-aligned instruction. This study is part of a larger, mixed methods research project that investigated grades 6-8 science teachers' NGSS enactment across California. This larger study was conducted in Fall 2018 through the end of Spring 2020 with public school STEM teachers in grades 6-8. Nineteen California teachers joined the project, 13 of whom were participants in a multiple-district NGSS implementation initiative. The other six teachers were from districts that were also in the process of implementing NGSS but did not participate in the implementation initiative.

A. Context of Study

This multiple-district NGSS implementation initiative brought together district leadership teams to design and implement NGSS adoption plans in advance of the regular schedule in California. The districts were required to take a comprehensive approach to implementation by developing policies and practices, administrator leadership, teacher leadership, professional learning opportunities, and networks among the districts (Tyler & Britton, 2018). To support these efforts, the initiative provided substantial financial resources and professional learning for NGSS implementation. From 2014-2018, study teachers in the initiative participated in optional professional development focused on transitioning teachers to the NGSS. There was a total of eight school districts that participated in the initiative, with approximately 400 teachers participating in the initiative (not all eventually participated in the research activities investigating the impacts of this initiative). Professional learning consisted of week-long summer institutes and two lesson-study cycles during the school year that focused on several aspects of the NGSS, including an emphasis on the following: the three NGSS dimensions, real-world phenomena-based lessons, and inquiry-based learning (Tyler & DiRanna, 2018). The summer institutes provided tools to teachers that supported their adoption and implementation of the NGSS (Tyler & DiRanna, 2018). One of these tools was using questioning strategies to push their students to engage in sensemaking and productive discourse; another tool was utilizing students' prior knowledge to engage students in this cognitive "heavy lifting." These tools align with definitions of epistemic agency and funds of knowledge in the literature, and as such, these constructs were included in the framework of analysis used by the research team that researched the impacts of the professional learning initiative. The following four districts participated in both the initiative and the research: Valley Creek (six participating teachers), La Paloma (two participating teachers), Kenmore (one participating teacher), and Glacier (four participating teachers).

Specifics were not known about the nature or quality of professional development in the districts that did not participate in the NGSS implementation initiative, including what attention was paid to the use of phenomena in science teaching; however, through interviews, researchers learned that teachers from these districts were provided much less NGSS professional learning and implementation support. Ravenview (with two participating teachers) and Tidewater (with four participating teachers) were the only two districts that did not participate in the initiative but did participate in the research.

None of the study teachers reported that their district or school had provided any NGSS-aligned instructional materials. As a result, the lessons observed in this study were created by the study teachers, either individually or with a few peers in their school and/or district. Classroom observations, surveys (both teachers and students), and interviews were conducted with the 19 teachers in the study. Interview and survey questions sought to understand whether or how California middle school teachers were implementing the NGSS, with special attention paid to components of the study's overarching framework: 3-dimensional learning, phenomena, coherence, epistemic agency, and equity.

B. Research Questions

I used the following research questions to guide my research: 1) How often did middle school science teachers across California create opportunities for students to activate epistemic agency in engaging with the science and engineering practices and to draw on students' funds of knowledge? 2) What opportunities for epistemic agency did middle school science teachers discuss and ultimately enact in their classroom by drawing on students' funds of knowledge? And 3) When teachers enacted epistemic agency by drawing on students' funds of knowledge, what was the student impact on how they saw science as relevant to them?

In this dissertation, to answer these research questions, I first present the two concepts that make up my conceptual framework and are defined using prior literature. Then, I discuss prior research that has been conducted in epistemic agency and funds of knowledge in middle school classrooms. Next, I present the methods for data collection and analysis and the findings from analyses of the teacher and student surveys, classroom observations, and interviews. I conclude with a discussion of the findings and highlight some important limitations, implications, and conclusions for this work.

II. Conceptual Framework

This study is framed by two concepts derived from prior literature: epistemic agency and funds of knowledge. In the following sections, I first discuss literature on agency more generally and then detail what epistemic agency is and its relationship to agency more specifically. Then, I provide an overview of literature regarding the second component of my conceptual framework: funds of knowledge. I conclude with presenting how epistemic agency and funds of knowledge are related and a figure that depicts the relationship between these two constructs.

A. Epistemic Agency

Below, I first discuss agency as a general concept and then I detail its relationship to epistemic agency, the first component of my conceptual framework. Agency has been discussed in psychology and related disciplines. Vygotsky (1980) argued that human activity is different from animal behavior because of its agentive component. Vygotsky stated that "it may be said that the basic characteristic of human behavior in general is that humans personally influence their relations with the environment and through their control" (p. 51). The defining characteristic of human behavior is activity which is enacted intentionally ("through their own control"). It is intentional action which humans use to improve their own lives as well as the lives of those around them. Vygotsky argued that the person at the center of activity has some level of influence on their environment and humans use tools in their environment to engage in higher level thinking. At the very core of human activity is agentive action.

However, Vygotsky also argued that human activity, and specifically learning, occurs in a social world. He stated, "Learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers" (p. 90). It is the interaction between a child and a more knowledgeable other that pushes the child along in their development. Thus, social interaction is crucial for learning and within these interactions are people enacting influence on their environment. This has implications for understanding how agency is negotiated between students and teachers in a classroom through social activity (e.g., learning).

Bandura (2006) offered a definition of human agency that is in line with pieces of Vygotsky's thinking on human activity and agency as social. Bandura contended that agency extends from the belief that human beings are active contributors to their environment, not simply products of their environment. Agency is conceptualized as a negotiated interaction between an agent or actor and other tools, people, or systems. There is no such thing as "absolute agency" (agency is not a dichotomous construct) since it is a construct that always exists by virtue of being human. Rather, it is mediated by interaction. In other words, humans always have agency, but the extent of their agency is constrained or supported by environmental influences. It is this mediation among the interpersonal, behavioral, and environmental that distinguishes agency from other constructs like free will. Agency is mediated.

While these core properties present one way to think about agency, questions have been raised about whether agency has been properly and thoroughly operationalized in the literature. Arnold and Clarke (2014) alleged that agency has remained a rather elusive term, lacking explicit operationalization in the literature. They recommended future researchers more clearly define agency as they use it in their research. In response to this call for more detailed and nuanced definitions of agency, I now narrow in on a specific kind of agency relevant to teaching and learning science: epistemic agency. It is this construct that makes up the first piece of my conceptual framework.

Epistemic agency extends the definitions of agency by focusing more specifically on how students are involved with the construction of shared knowledge objects (e.g., explaining a phenomenon) (Damsa et al., 2020; Ko & Krist, 2019; Miller et al., 2018). Epistemic agency is defined as students' participation in the process of iteratively shaping emerging knowledge goals and inquiry agendas (Scardamalia, 2002; Zhang et al., 2022). A helpful metaphor proposed by Pendleton-Julian and Brown (2018) describes epistemic agency as akin to white-water kayakers navigating fluid and fluctuating waters; in order to do this, kayakers need to constantly read the water and adjust their individual positioning within the context of the team. Thus, through epistemic agency, students are not just meaningfully participating in general class activities, they are participating in a knowledge building process with the teacher and their peers. Ko and Krist (2019) explained that while meaningful participation in classroom activities is important, the goal of current science education reforms is engaging students in the process of knowledge construction (e.g., through engagement in the science and engineering practices). Epistemic agency is students' involvement in both directing and monitoring the knowledge construction activities of a classroom community (Damşa et al., 2010; Miller et al., 2018; Stroupe, 2014). In order to be engaged in this way, students need to 1) make judgements about the state of their knowledge, and 2) make decisions about the direction of their knowledge building process (Ko & Krist, 2019). It is through enacting epistemic agency that students shift from merely learning about science to figuring out science (Zivic et al., 2018).

Ko and Krist (2019) highlighted collaborative interaction as a particularly important component of understanding what epistemic agency is. By "collaborative interaction", Ko and Krist explained that epistemic agency is a characteristic of a group involved in a knowledge building process; they contended that epistemic agency is not actually a construct at the level of the individual, but rather emerges from a group engaged in social interaction. Epistemic agency is still considered a dynamic, multidimensional construct which is negotiated through interaction. However, this stance on epistemic agency as a group-level construct only is somewhat contested, as will be explained later. Epistemic agency (like human agency generally) is a construct that students always possess; it is simply constrained or supported in various ways (Carlone et al., 2015). Epistemic agency shifts between those who have more or less power, but those with less power always retain some level of agency. For example, students can enact agency by choosing to subvert teacher defined expectations or norms; while the expectations or norms are set by the teacher acting as an epistemic agent, students still have some level of power to accept or defy these expectations.

Those who enact epistemic agency are referred to as epistemic agents. Stroupe (2014) advocated for expanding the student role in the science classroom towards not only learning the disciplinary content of science, but also participating in discursive knowledge generation that occurs in science as a collective practice. Teachers are thus encouraged to push students to take on the role of epistemic agents, or "individuals or groups who take, or are granted, responsibility for shaping the knowledge and practice of a community" (p. 488). Epistemic agents are those individuals who play a part in negotiating what counts as science as well as the processes of scientific investigations. When students are epistemic agents, students are given opportunities to take ownership of their learning and decide on the processes to achieve learning objectives (rather than teachers providing students with the instructions and parameters of what to learn). Students are thus positioned not as passive recipients of information, but as active "do-ers of science" (Miller et al., 2018, p. 3) who engage in science and engineering practices as professionals in these respective fields would.

Taken together, these various definitions of epistemic agency coalesce around two main components. First, epistemic agency involves students being able to identify what knowledge they have and what knowledge they need to achieve their own goal or the goals of their community. Second, agency is a discursive practice negotiated in interaction; the social, collaborative nature of human interaction is integral to understanding what agency is and how it shifts between teachers and students. Taken together, epistemic agency can be defined as students and their community (including teacher and peers) working together to identify the state of their knowledge and engaging in the necessary practices to further expand that knowledge in science classrooms. This means that students not only participate in figuring out what they know, but they also participate in figuring out how they know.

While there are similarities in the various definitions of epistemic agency, there is currently a lack of consensus in the literature about how to measure epistemic agency. In response to this gap, Zivic et al. (2018) proposed measuring epistemic agency along three main dimensions: 1) intellectual work, 2) social dimensions of the intellectual work, and 3) students' affective response to their classroom. For intellectual work, students can exhibit more or less epistemic agency depending on whether the teacher delivers content to students or whether students themselves engage in knowledge construction within their classroom community. For the social dimension, epistemic agency might be measured by attending to the social ways that students are engaged in a knowledge building process (e.g., whether they are engaged in group work). For the third and final dimension, the authors recommended attending to students' affective response about their own learning process (e.g., how what they did or learned in class mattered to them as an individual, mattered to the class, mattered to their community, or did not matter at all). This way of measuring epistemic agency attends to both the individual level of agency and agency as a product of group collaboration.

For the purposes of this study, I adopt the view that epistemic agency can be measured along the first two dimensions (Penuel et al., 2016; Zivic et al., 2018). I adopt these two dimensions because of the data collected in the study; student surveys asked students to respond to whether they thought content in their science classes mattered to them, but no further questions were asked about their feelings about their science class. Measuring epistemic agency along intellectual and social dimensions is in line with prior research that has examined differences between those who have more or less agency in order to understand who holds power and whose knowledge counts in the classroom (Berland et al., 2019; Cherbow, 2022; Damsa et al., 2010; Stroupe, 2014).

B. Funds of Knowledge

As will be discussed in the literature review in the following chapter, there have been calls for research that examines how teachers can enable epistemic agency in the classroom (Zhang et al., 2022). One tool that has been discussed is leveraging student's funds of knowledge (Calabrese Barton & Tan, 2009). By leveraging these funds, teachers can create avenues of access through which students can participate in inquiry building and scientific practices.

Moll et al. (1992) defined funds of knowledge as knowledges that are "historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" (p. 133). Such resources include knowledge about agriculture, business, economics, medicine, and household management. The authors explained that this concept is defined as being different from "culture" in the general anthropological sense because funds of knowledge, although connected to culture, is more precisely situated within the context of teaching and the classroom. The researchers argued that all students bring funds of knowledge to school and, therefore, these knowledges become potential resources for teachers to draw upon to inform their classroom instruction (Moll et al., 1992). A funds of knowledge approach is situated within an understanding of the sociopolitical histories and economic contexts of the households students come from. As such, funds of knowledge are specific cultural knowledges that are constructed through participation in complex social networks and pertain to people of a particular local region.

These social networks are not only the contexts within which funds of knowledge are constructed, but also through which such knowledge is taught and communicated. Moll et al. (1992) described social networks as possessing two major characteristics. First, these networks are "thick" and "multistranded", meaning that participants in these social networks often espouse many roles (e.g., an uncle teaches a child carpentry, but is also an integral member of the family unit acting as uncle, brother, and friend). Second, these networks are reciprocal, emphasizing symbiotic social interdependence among its members. Reciprocity in this sense indicates that funds of knowledge are constructed through lasting social relationships and are not taught in a unidirectional manner; children are given the opportunity to learn through active participation in activities that teach various funds of knowledge and in turn, teachers learn from students and their communities. These kinds of intricate social networks that Mexican-American students in the study were found to be familiar with at home through research were contrasted with traditional "single stranded" student-teacher relationships in formal classroom contexts (p. 134).

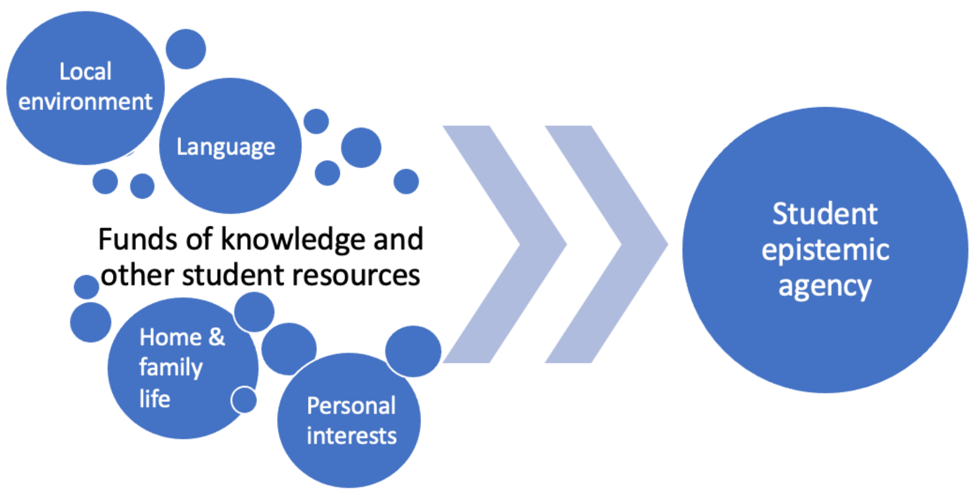
Much previous work has been done utilizing a funds of knowledge perspective in science education research. This project adopts an expanded definition of funds of knowledge beyond the original definition (Moje et al., 2004). In addition to funds nested in student's home life, students bring other resources that are valuable for science learning, such as their personal interests and talents, concerns about socioscientific issues, and prior content learning (Calabrese Barton & Basu, 2007; Calabrese Barton & Tan, 2009; Campbell et al., 2016). These are important resources to attend to and when leveraged effectively create an opportunity for students to engage in school science from a place of community knowledge/knowing. For the above reasons, student funds of knowledge makes up the second component of my conceptual framework.

C. Epistemic Agency and Funds of Knowledge

As mentioned earlier, previous literature has called for research that identifies practices which increase teacher enactment of epistemic agency in the classroom (Zhang et al., 2022). Further, prior research has problematized a funds of knowledge approach for neglecting issues of agency and thus, not going far enough in empowering students and their communities to participate in the sciences, especially historically minoritized students (Rodriguez, 2013). In response to these calls, this study is framed by both constructs: epistemic agency and funds of knowledge. Funds of knowledge is conceptualized in this study as a strategy that teachers can use to enact epistemic agency. Figure 1 below depicts the relationship between epistemic agency and funds of knowledge. In this figure, language and home and family life are given as some examples of many kinds of student funds, represented by the smaller bubbles without text. The funds of knowledge considered in this study's analysis are not limited to those depicted in the figure. For visual space and aesthetic reasons, some funds have been removed from the figure but can be found in the funds of knowledge coding scheme in the methods.

Figure 1

Epistemic Agency and Funds of Knowledge Conceptual Framework



Note. The funds of knowledge considered in this study's analysis are not limited to those depicted in the figure. For visual space and aesthetic reasons, some funds have been removed from the figure but can be found in the funds of knowledge coding scheme in the methods.

III. Literature Review

In this chapter, I discuss what previous literature has said about the two constructs of interest to this study -- epistemic agency and funds of knowledge -- as well as what research has been done about these two constructs in connection with each other. This chapter will bring clarity to the gaps that exist in the literature about how teachers enact student epistemic agency by drawing on their funds of knowledge.

A. Epistemic Agency

Recent calls for education reform have shifted discussion from students learning about science to students doing the intellectual work of figuring out science (Cherbow, 2022; National Research Council, 2012; NGSS Lead States, 2013). As such, there has been much literature about how secondary science teachers support students in the intellectual work of figuring out.

Previous literature on epistemic agency in secondary science classrooms have examined how single teachers or small groups of teachers have used NGSS instruction to support epistemic agency. Gonzalez-Howard and McNeill (2020) took a very fine-grained approach to examining teacher moves and classroom discourse using a social network analysis approach. This analysis included looking at classroom observations but did not include interviews or surveys in their analysis to measure how teachers or students perceived or conceptualized epistemic agency. Their sample included three 6^{th} or 7^{th} grade teachers across two different schools. They found that focusing on how teachers scaffold engaging in argument from evidence and critique is one important pedagogical practice for shifting away from traditional authoritative instruction. Several other studies have taken a case study approach to understanding how secondary science teachers enact NGSS and epistemic agency (Cherbow & McNeill, 2022). Cherbow and McNeill (2022) examined how one teacher enacted epistemic agency using OpenSciEd storyline units. This case study teacher had extensive experience in physical science and engineering that is not necessarily typical of every teacher, as well as 15 years of teaching experience. The authors found that this teacher's deep teaching experience and passion for reform-oriented instruction uniquely positioned him as capable to partner with students in developing and managing the direction of their knowledge-building goals. The authors considered that perhaps less experienced teachers or teachers with limited experience with reform efforts might be less likely to engage students the way their case study teacher did. In summary, these two studies examined epistemic agency in middle school classrooms in the context of one unit (Cherbow & McNeill, 2022; Gonazalez-Howard & McNeill, 2020). Overall, previous studies have predominantly examined single classrooms or single teachers in the context of a unit or specific lesson.

There has been some prior work that has included more teachers and/or students in their study sample when examining epistemic agency in secondary science classrooms. For example, Stroupe et al. (2018) examined student epistemic agency by looking at one sixth grade teacher with three classes of 30 students each (a total of 90 students) across 22 instructional days. The unit under study was co-constructed by the case study teacher along with researchers. The unit development was a very iterative process with heavy involvement from teaching and content experts. In this study, both the teacher and researchers grappled with tensions when students' questions took the unit in a different direction and how to support these spontaneous questions while still engaging in the unit as planned. This meant navigating inherent uncertainty and chaos.

In an earlier study, Stroupe (2014) included five first-year teachers, four who taught high school and one who taught middle school. In this study, three teachers who encouraged students to participate in sensemaking gave students more opportunities to take and use cognitive authority (e.g., allowing students to solve problems that had meaning in their lives), hold each other and teachers accountable for participatory norms, and use resources (e.g., enough time to complete assignments and engage in a safe discourse-rich environment) when compared to the two teachers who adopted a science-as-accumulated knowledge perspective. This study also incorporated more data sources in its analysis, including interviews, observations, and classroom artifacts. As a related example, Ko and Krist (2019) included a sample of 24 middle school science teachers across five schools. This sample is very similar to the one used for this dissertation study. However, Ko and Krist analyzed how teachers used a specific curriculum (the Investigating and Questioning our World through Science and Technology curriculum) to open up epistemic space for students in their classrooms. Findings showed that there were three aspects of the NGSS that provided teachers an in-road towards shifting their teaching practice towards one that fostered epistemic agency for students: involving students in deciding on the methods of investigation, allowing students to make personal connections to anchoring phenomena (e.g., drawing on their home and family life as a way to make sense of phenomena), and supporting students in constructing explanatory models for observed phenomenon. Further, these authors argued that the tension found in Stroupe's (2014) study is an important part of the everyday decision making that teachers already do; in other words, they advocated for embracing tension between teaching for epistemic agency and teaching for standards because they view these forms of teaching as not mutually exclusive. Taken together, this previous work has revealed important findings related to epistemic agency in secondary science classrooms; however, most of this work has included smaller sample sizes than the study detailed in this dissertation.

Further, some previous literature on epistemic agency in secondary science classrooms has focused on how students engage in one of the SEPs, such as engaging in argument from evidence (González-Howard & McNeill, 2020) and planning and carrying out investigations (Stroupe et al., 2018), or several SEPs together (Penuel et al., 2022). The work presented here aims to expand on prior literature by examining multiple classrooms and teachers, within a single day or two of instruction, integrating all or several SEPs into their instruction. Indeed, the study described in this dissertation expands on previous work in several ways, which will be described further below.

B. Funds of Knowledge

Much has been written about funds of knowledge approaches in secondary science education over the last three decades and has shown that when students see a connection between science learning and their lived experiences outside of school, they see science as being meaningful for their lives and communities (Barton, 2001; Calabrese Barton & Tan, 2020; Razfar & Nasir, 2019; Upadhyay, 2006). Further, the NGSS explicitly call on teachers to leverage students' funds of knowledge, saying, "Effective teachers ask questions that elicit students' funds of knowledge related to science topics. They also use cultural artifacts and community resources in ways that are academically meaningful and culturally relevant" (NGSS Lead States, 2013, p. 7). In response to this call, researchers have attended to what kinds of funds of knowledge teachers draw on to engage students in the practices of science.

Previous research on secondary science classrooms has found that connecting scientific concepts with cultural and household objects improved the engagement and comprehension outcomes for a group of six bicultural students in a 7^{th} grade class (Kim et al., 2021). Furthermore, prior research has found that when teachers can successfully integrate students' cultural knowledge into their curriculum, there are positive influences on learning outcomes (Delpit, 1995; Ladson-Billings, 1995). However, this requires teachers (a predominantly White, female workforce) to be open to learning *from* students about experiences that are likely very different from their own everyday experiences (Upadhyay, 2006). One study by Irish and Kang (2018) of 57 middle school students and their three teachers found that, despite teachers' attempts to facilitate connections between scientific concepts and students' funds of knowledge, students reported not being able to relate to the content.

In fact, some prior research has criticized funds of knowledge approaches for not going far enough in disrupting traditional classroom power dynamics such that teachers and students learn from each other (Rodriguez, 2013). While previous literature has focused on a funds of knowledge approach related to curriculum and instruction, Rodriguez argued that there has been less emphasis on the 'why' of funds of knowledge, which is to engage and empower students and their communities. In other words, issues of enacting student agency in the classroom are deeply relevant to a funds of knowledge approach, yet not deeply interrogated. Viewing students as co-constructors of knowledge within the classroom ascribes agency to students in a system that views them as boxes to be filled with knowledge. A funds of knowledge approach is not simply about tolerating different experiences or viewpoints, but about meaningfully integrating students' lived experiences in such a way that empowers students, their families, and their communities to engage in science. Prior research has identified that leveraging the valuable resources that students do possess positions students as having a right to participate in learning science (Gutierrez, 2008; Moje et al., 2004). Therefore, prior research has called for funds of knowledge approaches to incorporate student agency as a construct for research. Funds of knowledge as a singular approach is not sufficient; epistemic agency must also be considered.

C. Epistemic Agency Connected to Funds of Knowledge

Additionally, within epistemic agency literature on secondary science classrooms using NGSS, little research has been done relative to connecting epistemic agency and funds of knowledge (González-Howard & McNeill, 2020; Penuel et al., 2022; Sezen-Barrie et al., 2020). A study by Miller et al. (2018) did touch on integrating student and community knowledges into instruction in the context of a case study but did not incorporate funds of knowledge more specifically into their framework for analysis. However, this study makes a strong case for the importance of integrating epistemic agency and funds of knowledge approaches to avoid epistemic injustice or epistemic oppression. This happens when student's epistemic agency is consistently undermined, whether intentionally or without reason. When students are repeatedly prevented from seeing their capacity to think through problems as valuable (prevented from seeing themselves as epistemic agents), they may come to see themselves as not capable of doing science. This injustice is significant not only for individual students, but over time becomes significant for the communities of which they are a part. Redistributing power and opening up the dialogic space in the classroom for student participation is thus incredibly important for developing students' abilities to engage in the practices of science.

Prior research has problematized the NGSS as simply another set of standards documents that suggest students be “doers” of science, so long as they are doing the science that is outlined in the standards (Miller et al., 2018). That is, standards-sanctioned science is the science that students should be doing and is insufficient if instruction only goes so far as eliciting student ideas that are recognizably aligned to the standards. An important finding from this study was that drawing on students’ lived experiences was insufficient for engaging students’ epistemic agency; in other words, teachers needed to go beyond “complacent approaches to NGSS enactment” by not only setting up an initial community-based problem or phenomenon, but also eliciting students’ ideas that are divergent from the standards. The authors argued that there must be more research done on whether or how opportunities are provided for students’ home and community-based intellectual resources to be seen as valuable science work.

The study described in this dissertation is more naturalistic and examines what teachers do without extensive support from researchers in place (Stroupe et al., 2018). The study in this dissertation expands on this previous work by including a larger sample of specifically middle school teachers, with varying teaching experience and content knowledge (Cherbow & McNeill, 2022; Gonazalez-Howard & McNeill, 2020). This study also includes several different data sources from both students and teachers to try to capture their rich experiences in the classroom. Further, in the current study, I did not examine any one specific curriculum, but rather how teachers’ instruction draws on epistemic agency in the context of a widespread standards implementation endeavor.

As such, the current study is opportune because of the variety of NGSS implementation supports and teacher buy-ins. In a naturalistic setting, I investigated NGSS implementation with a range of professional learning and district support. I asked how did middle school science teachers provide student's epistemic agency, specifically by drawing on students' funds of knowledge? Furthermore, this dissertation contributes to literature on epistemic agency more broadly by including a larger sample size and looking at implementation of several SEPs. This research seeks to extend the literature by examining how middle school science teachers not only draw on students' funds of knowledge but draw on these funds in such a way as to engage them in developing their epistemic agency.

IV. Methods

I utilized a mixed-methods approach to answer my research questions (Creswell, 2017). As a reminder, the research questions were: 1) How often did middle school science teachers across the state of California create opportunities for students to activate epistemic agency in engaging with the science and engineering practices and draw on students' funds of knowledge? 2) What opportunities for epistemic agency did middle school science teachers discuss and ultimately enact in their classroom by drawing on students' funds of knowledge? And 3) When teachers enacted epistemic agency by drawing on students' funds of knowledge, what was the student impact on how they saw science as relevant to them? To answer these research questions, I analyzed several data sources using both qualitative and quantitative methods.

A. Context of the Study

As mentioned in the introduction, this project extends from a larger project investigating grades 6-8 science teachers' NGSS enactment in California across two years (Fall 2018-Spring 2019 and Fall 2019-Spring 2020). A total of 19 California teachers participated in the project. They can be organized into three groups based on the type and amount of professional learning they received (none, moderate, and extensive, explained further below). Thirteen of these teachers in the Valley Creek, Kenmore, Glacier, and La Paloma districts received professional learning as part of an initiative for early implementation of the NGSS (Tyler et al., 2020). This professional learning was extensive in that it was offered over a prolonged period of time (several years). The five teachers in the Tidewater district received comparatively less NGSS professional learning. Teachers in the Tidewater district did receive some professional learning from their district, but it was not sustained over several years. The final two teachers in the Ravenview district did not receive any professional learning from their district regarding NGSS and any professional learning that teachers did report engaging in was received through their county. While this analysis will not examine the specifics of the various professional learning opportunities that were offered to teachers in these districts, this is important contextual information to know about the kinds of professional learning resources teachers had available to them. It is also important to note that although the professional learning was offered, it was not mandatory in any district, and as such, the reported hours of professional learning that various teachers engaged in did not necessarily align with whether the district support level was labeled as "extensive", "moderate", or "none."

Recruitment of these 19 teacher participants was done through multiple means: by working with district science leaders to solicit teacher participation, and through word-of-mouth communication among teachers by asking participating teachers to recruit a colleague. By recruiting using multiple means, and not having strict exclusion criteria (they needed only to be teaching science in grades 6-8 at one of the six participating districts), participants included middle school science teachers who had a range of familiarity with, views about, and support implementing NGSS instruction.

A team of 12 researchers conceptualized and designed the study instruments and collected all the data. The team of researchers included research assistants, research associates, and principal investigators at WestEd with expertise in education generally and most had expertise in science education more specifically. I did not assist with any of the instrument design or data collection; three other graduate students and I were brought on to the team after data were collected to assist with data analysis for the project.

B. Teacher and Student Participants

Participants taught across six districts; these participating school districts varied in size, location, and student demographics and received varying levels of NGSS implementation support. All participant names (including student names) and district names are pseudonyms. Table 1 below clusters the teachers according to how much support their district provided for professional learning. The Ravenview district provided no NGSS professional learning to their teachers and thus, any professional learning these teachers did participate in for NGSS support was voluntary and done through their county. This level of district support was labeled “none.” The Tidewater district support was considered “moderate” because they did offer professional learning to their teachers, but it was only offered for one year. The teachers in the Glacier, Kenmore, La Paloma, and Valley Creek districts were a part of a more extensive NGSS implementation endeavor that involved professional learning offered across six years. These districts were labeled as “extensive” because the professional learning was offered longitudinally.

The study presented in this dissertation examined a total of 19 predominantly female and White case study teachers from these six school districts (see Table 1 for teacher demographic information). As stated above, the table is organized by district level of NGSS support (extensive to none). Within the extensive to none ranking, districts were put in alphabetical order, and then teachers within these districts were listed in ascending order of the grades they taught (6th to 8th grade).

Table 1

Teacher Participant Information

Name	Sex	Race/Ethnicity	School District	Grade Level Taught	Level of District NGSS Support	Hours of professional

						learning (2015-2019)
Natasha	F	Prefer not to state	Glacier	6th	Extensive	80+
Andrea	F	White	Glacier	6th	Extensive	80+
Lindsey	F	Prefer not to state	Glacier	8th	Extensive	80+
Louise	F	White	Glacier	8th	Extensive	36-80
Louis	M	White	Kenmore	7th	Extensive	36-80
Katie	F	White	La Paloma	6th	Extensive	16-35
Kiara	F	White	La Paloma	6^{th}, 7^{th}, 8^{th}	Extensive	Missing*
Megan	F	Prefer not to state	Valley Creek	6th	Extensive	6-15
Jasmine	F	White	Valley Creek	6th	Extensive	80+
Lily	F	Asian	Valley Creek	7th	Extensive	Missing*
Kelsey+	F	White	Valley Creek	7^{th}, 8th	Extensive	80+
Stacy	F	White	Valley Creek	8th	Extensive	80+
Jessica^	F	White	Valley Creek	8th	Extensive	6-15
Lydia	F	Hispanic/Latino	Tidewater	6th	Moderate	16-35
Diane	F	White	Tidewater	7th	Moderate	80+
Amelia	F	White	Tidewater	7^{th}, 8th	Moderate	36-80
Adrian	M	White	Tidewater	8th	Moderate	36-80
Kiley	F	White	Ravenview	7^{th}, 8^{th}	None	6-15
Desiree	F	White	Ravenview	7^{th}, 8th	None	6-15

Note. ^Missing student survey data for the 2018-2019 school year. +Missing observation notes for the Spring 2019 semester. *Missing because they did not respond to this question in the survey.

Students in the study were the students of 18 of the 19 teacher participants; one teacher participant did not disseminate the survey to their students. Teachers gave the students surveys in all the classes in which they taught science; this meant that some teachers had more student participants than others depending on how many science classes they taught in a semester. In total, there were 886 student respondents in Spring 2019 and 548 student respondents in Spring 2020. In total, 1,434 students completed surveys in both years. Of the 904 students in both surveys who responded to demographic questions (not all students responded to all questions), 21% were in 6^{th} grade, 21% were in 7^{th} grade, and 57% were in 8^{th} grade. Students were 48% female and 46% male; 6% declined to state. The majority of students were either Latinx (42%) or White (37%). Students were also asked what languages they spoke. This information can be found in Table 2 below. Note that the percentages do not add up to 100 because students could mark that they spoke more than one language.

Table 2

Student Self-Reported Language Spoken

Language spoken	Responses
English	97%
Spanish	40%
Chinese (Mandarin or Cantonese)	4%
Tagalog/Filipino	2%
Vietnamese	1%
Korean	3%
Other	11%

Student race/ethnicity data are reported in Table 3 below. Like the language survey question, the percentages do not add up to 100 because students could mark multiple races or ethnicities.

Table 3

Student Self-Reported Race/Ethnicity Information

Race/Ethnicity	**Responses**
Decline to state	4%
African American	5%
Latinx	42%
Native American	5%
Asian	19%
Pacific Islander	4%
White	37%
Other	14%

C. Data Collection

For each year of the two years of this study, these 19 case study teachers were asked to complete one or two classroom observations with accompanying pre-, mid-, and post-observation interviews. In the first year of the study, teachers were asked to participate in one classroom observation; in the second year of the study, the number of observations was increased to two, and an accompanying mid-observation interview was added in between the two observations. Teachers were also asked to complete an end of year interview, a teaching log (in which they submitted student work and instructional materials for a unit of instruction), and an end of year teacher survey. Finally, they also disseminated surveys to their students once a year. See Table 4 below for a timeline of what data sources were collected when. Study activities were impacted by the COVID-19 pandemic in Spring 2020; only survey data were collected from teachers in the spring semester. The work presented here examined observation, interviews, and survey data across three semesters (Fall 2018, Spring 2019, and Fall 2019) and only survey data from Spring 2020. Table 4 provides information on what data sources were collected in which semesters and more detailed information on each of these data sources follows this table.

Table 4

Timeline of Data Collection

Year	Semester	Data Source
2018	Fall	Classroom observation (1 day) Observation interviews
2019	Spring	Classroom observation (1 day) Observation interviews Teacher end-of-year survey Student end-of-year survey
2019	Fall	Classroom observation (2 days) Observation interviews
2020*	Spring	Teacher end-of-year survey Student end-of-year survey

Note: *This semester is missing classroom observation and interview data due to COVID-19 pandemic and school closures.

1. Classroom Observations and Accompanying Interviews

Researchers conducted observations to see how teachers implemented NGSS instruction; there was no explicit prompt given to teachers that their lessons would be studied for any specific construct (e.g., funds of knowledge or agency). Researchers took photographs of how the classroom was configured (e.g., where desks were located, how they were grouped, and where the teacher conducted most of their instruction), work that was completed on the board, sample student work, and any classroom posters on the walls. During their observations, researchers also took field notes that captured what was happening in the classroom related to enacting NGSS; this included notes on both the students' experiences (student engagement and roles) as well as teacher practice (teacher actions). Specifically, field notes attended to teacher and student discourse as well as a description of lesson activities (e.g., teacher and student actions). The field notes protocol asked researchers to attend to approximate times spent on different lesson activities (length in minutes), student and teacher participation structures, and the main activities of the class. They were also asked to attend to the instructional materials used, the physical classroom environment, and any specific NGSS elements they observed. See the Appendix for the full field notes protocol.

During the 2018-2019 school year, observations of a single class period in the 19 case study teachers' classrooms were completed alongside pre- and post-observation interviews. During the Fall of 2019, observations of two consecutive lessons (2 days) with pre-, post-, and mid-observation interviews were done. Table 5 shows the schedule for interviews and observations in both years, with an additional day of observation as well as a mid-observation interview added in for year 2.

Table 5

Classroom Observation Data and Schedule

Year 1 Observation Schedule	Observation step	Time	Data Collected
	Pre-observation interview	30 min	Interview audio & transcript
	Classroom observation	Full class period	Field notes
	Post-observation interview	30 min	Interview audio & transcript
Year 2 Observation Schedule	Pre-observation interview	30 min	Interview audio & transcript
	Classroom observation (Day 1)	Full class period	Field notes
	Mid-observation interview	15 min	Interview audio & transcript
	Classroom Observation (Day 2)	30 min	Field notes
	Post-observation interview	30 min	Interview audio & transcript

Interviews lasted approximately 30-45 minutes, except for mid-observation interviews, which were shorter and approximately 10-20 minutes in length, and were conducted either over the phone or in person. The interviews were semi-structured (Brenner, 2006), starting with a series of open-ended questions and follow-up prompts to elicit additional details to encourage detailed responses. All interviews were audio recorded and later transcribed for analysis. The protocol for which all semi-structured interviews originated is provided in the Appendix.

2. Teacher End-of-Year Survey

All study teachers were surveyed about their instruction at the end of each academic year. The surveys were extensive and covered a range of topics relating to NGSS implementation, teacher background, school and district context, and professional learning. Among those questions were items taken from the National Survey of Science & Mathematics Education conducted by Horizon Research, Inc. (Banilower, et al., 2018) and the Science Teaching Efficacy Belief Instrument for in-service teachers (STEBI-A; Enoch & Riggs, 1990). These latter survey items focused on teachers' pedagogical beliefs related to effective science teaching and learning. Additionally, there were questions about what SEPs teachers enacted in their classrooms with students. In total, there were 131 closed-ended survey questions.

I chose to focus on a subset of 48 survey items that pertained to who was doing the cognitive work (epistemic agency) and questions related to student funds of knowledge (e.g., making connections between students' everyday lives and what is done in science class). To clarify, the questions analyzed for epistemic agency and funds of knowledge, respectively, can be found in the Appendix. The epistemic agency questions were survey questions which asked teachers how often they had students do the SEPs, which is how I operationalized epistemic agency (when and how often students were doing the practices). The epistemic agency questions were conceptualized by the research team to align with the NGSS SEPs and were intended to measure how often students had opportunities to do the SEPs in their science class during the year. Funds of knowledge was operationalized in the surveys as those questions which asked about how often teachers gave students opportunities to act on a science issue or topic in their school or community, encouraged student interest in science, made connections to students' everyday lives, or leveraged students' prior knowledge, among others listed in the Appendix. These questions were taken from the National Survey of Science & Mathematics Education conducted by Horizon Research, Inc. and were intended to measure teachers' attention to equitable practices. In this study, I interpret these equitable practices as the use of funds of knowledge because drawing on students' funds is an equitable practice. Further, these questions ask about how often teachers draw on student interests, prior knowledge, and community knowledge which are types of student funds.

3. Student Survey

As introduced above, this study also included student survey data. The project team developed an end-of-year student survey which included a subsection of questions about epistemic agency. The survey asked students about their science instruction during the 2018-19 and 2019-20 school years. For example, the survey questions highlighted which SEPs they recalled engaging in during class and where these practices originated from (e.g., the teacher, the textbook, or students themselves) among other topics. Student surveys mainly focused on questions related to epistemic agency and funds of knowledge; as such, half of the 22 total questions are included in the Appendix. Only questions related to demographic information have been omitted in the Appendix (e.g., who their science teacher was, race/ethnicity, language spoken, etc.). See the Appendix for the student survey questions relevant to this dissertation.

The student survey was administered by 18 of the 19 case study teachers to a total of 886 student respondents in Spring 2019 and 548 student respondents in Spring 2020. In total, 1,434 students completed surveys in both years. However, not all 1,434 students responded to every question, so response rates varied per item.

D. Data Analysis

The analysis for this study was both quantitative and qualitative and proceeded in several phases, some of which occurred concurrently. First, I began by analyzing the teacher interviews and observations from 2018-2019. Next, I analyzed teacher surveys and student surveys (in that order) from both study years. Finally, I analyzed teacher interviews and observations from the second study year. Below I discuss what analyses were conducted using these various data sources.

1. Qualitative Analysis

I utilized a combination of a priori and emergent coding (Strauss & Corbin, 1994) related to student epistemic agency (see codes in Table 6 below) and funds of knowledge (see Table 7 below) to code the pre-, mid-, and post-observation interview data as well as the end-of-year interviews from participating teachers. Analysis of these data sources allowed for examination of how teachers themselves reported enacting epistemic agency and drawing on student funds of knowledge. Coding of the classroom observations with accompanying interviews and the end-of-year interviews was done in two rounds using Atlas.ti. In the first round, I examined epistemic agency and conducted multiple cycles of coding within this round. In the second round, I analyzed the data sources for funds of knowledge. A description of these two rounds follows below.

To help ensure the trustworthiness of the qualitative analysis, intercoder reliability was checked. For the epistemic agency coding round, a study team member and I coded 50% of the interview and classroom observation data independently and then checked our coding for accuracy, achieving a Cohen's kappa of 0.84. Differences in coding were discussed; through discussion, we also established our emergent codes. The latter 50% was coded independently by me and I met as-needed with the other researcher to discuss any issues or questions that arose when coding. A different process was used for the funds of knowledge coding. I conducted most of the qualitative coding analysis for funds of knowledge. I had another study member complete an analysis of 20% of the data (with a mix of observation and interview data sources as well as different participants) and achieved a Cohen's kappa of 0.91 with this person. This person used the same coding scheme for funds of knowledge outlined below.

In the first round of coding, to answer my second research question, I analyzed the data for discussion or observation of epistemic agency by drawing on students' funds of knowledge. To record instances in the data where a teacher either discussed enacting epistemic agency in their interviews or was observed enacting epistemic agency in their observations, myself and my research partner developed a Cycle 1 code named "intellectual work of figuring out." This code was primarily defined by using the science and engineering practices since these were actions that we could observe and count. We coded through all teacher interview and observation data using only the "intellectual work of figuring out" code. This first pass for epistemic agency is referred to as "Cycle 1" in the codebook.

After reviewing all study teachers' data sources and conducting an initial pass for epistemic agency, I then added the Cycle 2 codes which emerged from analysis in Cycle 1. To narrow down the number of observations and interviews for coding to allow for a more in-depth investigation, I identified the top teacher in each of the six districts for a total of six teachers that reported the highest epistemic agency and funds of knowledge combined average score (these scores can be found in Table 11 in the first findings chapter as well as in Figure 6). I coded all the references in these six teachers' interviews and observations which had previously been coded as "intellectual work of figuring out" but this round I coded for the Cycle 2 codes. These second cycle codes were developed by attending to who was doing the activity that was either being observed or discussed (whether that was the student doing the activity, teacher doing the activity, or student and teacher working together). Definitions of these codes can be found in Table 6. Like in Cycle 1, I coded for one teacher with the Cycle 2 codes before moving on to the next teacher. Cycle 1 and Cycle 2 codes can be found in Table 6.

Table 6

Qualitative Coding Descriptions for Epistemic Agency

Cycle 1 codes			
Code name	Code description	Example	Rules
Intellectual work of "figuring out"	An instance where there is some activity or opportunity (either implicitly or explicitly) for activity occurring around figuring out a science concept or a phenomenon in the world This is a larger level 1 code for us to identify when there is some kind of NGSS-aligned intellectually demanding activity This code is defined by SEPs – look for instances of SEPs first to code	Anytime students or teachers are engaged in SEPs (explaining, communicating information, collecting data, asking questions, etc.) Anytime students or teachers are engaged in hands-on or inquiry activities This includes labs, exploration activities (e.g., placing different size/weight balls on bedsheet to explore mass and gravity) Anything that is phenomena based (e.g., central question or problem to solve) Teacher reflects in their interviews about the intellectual work that happened in their lesson	Whenever figuring out is happening, <u>regardless of who does it</u> Figuring out does not include passive listening, acquiring knowledge through traditional lecture format If the teacher is sharing how others have "figured out" something, it should still be coded
Cycle 2 Codes: Possible to use multiple codes if applicable in one reference. If unclear who is doing the work, do not code. There were also codes for challenges regarding student doing activity, which was included in the coding round for funds of knowledge (in a separate table below).			
Student doing activity	Students doing the intellectual work	Student asks for materials for an investigation or engineering problem and teacher provides those material Student debate where teacher is listening Teacher poses a guiding discussion question for	This should be considered a high-level code (only use when it's very clear that students are directing the intellectual work of "figuring out") It is possible to use student and teacher in the same unit of analysis

		students to ponder and respond themselves (teacher is eliciting *student* ideas)	
Teacher doing activity	Teachers are doing the figuring out. This might be the teachers doing this *for* students or *instead of* students.	Teacher is giving a whole class presentation	
Guiding intellectual work of "figuring out"	Teacher provides an activity or opportunity in which they try to get the students to do the work of figuring out Teacher scaffolded instruction Teacher providing opportunities for students to engage in figuring out (a teacher move to give students opportunities for agency)	Teacher provides guiding, open-ended questions (either verbally or on worksheet) for students to work through Student asks a question that teacher does not know and they work together to find the answer	These codes capture what the teacher is doing (we are interested in activity, not teacher belief)
Anti-guiding intellectual work of "figuring out"	Teacher makes moves to limit opportunities for student agency	Teacher provided step-by-step lab instructions Teacher discusses challenges with engaging students in student driven work Teacher limits students from taking agency in asking a question or engaging in SEPs	

While I was coding for the second cycle epistemic agency codes, to answer the latter half of research question two, I also coded for teachers reported use of students' funds of knowledge. For this part of the analysis plan, I analyzed all epistemic agency references across interview and observation data for evidence of discussion or observation of drawing on student's funds of knowledge. Since my study seeks to understand how teachers use funds of knowledge to engage student's epistemic agency, it made sense to focus on discussion or presence of funds of knowledge only when teachers were also discussing or engaging students' epistemic agency. I adopted the same process as used for epistemic agency to develop a coding scheme for funds of knowledge (e.g., leveraging a mix of a priori and emergent coding techniques that emerged through discussion with my research partner). I adopted an a priori framework to identify several different types of funds of knowledge (Carpenter et al., 2020). Table 7 below provides the codebook used for this round of coding.

Table 7

Qualitative Coding Descriptions for Funds of Knowledge

Code name	Code description
Community or local geography/environment	Local community (e.g., using local sites like the library, community centers, museums, etc.) AND/OR participant discusses local geography and/or environment (e.g., earthquakes in CA, a local stream, local plant life)
Culture	Teacher discusses students' culture(s), or cultural practices and products connected to identity (e.g., food, music specific to cultural group, holidays etc.)
Everyday science experiences or examples	Teacher discusses science topics or examples related to students' everyday life experiences (e.g., enzymes in laundry detergent) Includes students' personal health, well-being, bodies
Home/family life	Teacher discusses students' home life and/or experiences with family members (e.g., parents and their work outside the home, work occurring in the home, siblings, family background, travel with family)
Language/linguistic resources	Teacher discusses language(s) other than English; students' home language(s) OR everyday language, academic language. "Home language" counts as both language and home/family life. Providing materials available in home-language or translated materials
Personal interests/identity	Teacher discusses students' personal interests (e.g., interest in animals; sports). Interest or lack of interest in subject area (including students seeing/not seeing themselves as a science/math person). Relevance to future careers – implicit connection to students' career interests. Intrinsic motivation; interest in school

	Making something "interesting" does not count. Difference between tapping into existing interests vs. making topic engaging, exciting, fun.
Pop culture	Teacher discusses pop culture (e.g., current music, movies, television, comic books)
Prior content knowledge	Students' prior content knowledge or skills, or "abilities" (e.g., content knowledge from previous courses or earlier in the same course or from prior STEM learning experiences). Includes students' naïve science views
Socioscientific issues and/or global context	Teacher discusses social or global issues (e.g., climate change, GMOs) AND/OR participant discusses geography or environment in general (not local). Includes living in another country
Other or non-specific	Teacher discusses types of knowledge or resources not included in the other codes. OR participant does not specify types of knowledge or resources (i.e., is general or vague). Making lessons or content "relatable" to students counts here
Challenges	Teacher describes challenges or uncertainty regarding students' backgrounds, prior knowledge, experiences, everyday life, language, cultural strengths, contexts, or other resources. References that address teaching and/or learning as a challenge in a general way
Reflection or awareness of growth	Teacher has awareness of their own deficit thinking AND/OR awareness of growth or needing to grow related to students' backgrounds, prior knowledge, experiences, everyday life, language, cultural strengths, contexts, or other resources
Deficit or Lack of resources	Teacher talks about students' lack of funds of knowledge or resources (e.g., parents unavailable to help). Brings up what students lack or what students don't have
Critical lens or perspective	Teacher discusses ways science has been used to silence or marginalize certain groups (e.g., how most scientists are white men, how few studies about human health have focused on women and/or people of color, how indigenous knowledge has been ignored) AND/OR participant discusses ways to use science for speaking out against bias and injustice (e.g., participant discusses intentionally asking open-ended questions with no single "right" answer, engaging students in a social action project, sharing research with leaders or community to enact change, doing a school or community study or walk, introducing BIPOC and female scientists; giving equal voice to all students) AND/OR participant recognizes role of teacher in critical perspectives – discusses their own cultural positioning; discusses being able to learn FROM students. Acknowledging problematic

	systems or structures in education – e.g., with tracking, tracking as racialized

Note: Coding scheme adopted from Carpenter et al. (2020) with minor changes.

Using this multi-round approach to data analysis, I report on general trends across data sources across years in the findings chapters. I report on higher level themes related to how the relationship between epistemic agency and funds of knowledge looks like in the context of NGSS-aligned, California middle school classrooms. Themes that emerged from the data were derived from the coding framework described above and by analyzing how frequently each of these codes were observed. I examined how frequently each code was counted in the data to identify the broad range of perspectives or experiences that were found in the data (Saldaña, 2015). I used the counts to explore how participants discussed the two constructs of interest. I further explored the information within these counts by delving deeper into the classroom observations of two teachers in particular (Stacy and Katie). These were two teachers who had the most instances of *student doing, teacher doing,* and *guiding* activity. I adopted a data visualization tool meant to reveal patterns in whole-class discussions (Colley & Windschitl, 2020). This tool captures the dynamic interplay between students and teachers during whole-class discussions much like transcripts do, but more effectively distills these data into a barcode-like visual that is more easily interpretable for readers and researchers. I adopted and slightly modified this tool to look at not only whole-class discussion but activity units to synthesize case study teacher observation data. An activity unit was defined by the beginning and ending of an activity happening in class; for example, watching a video from beginning to end was one activity unit, student discussion about the video was a separate activity unit, and filling out a worksheet after the discussion was a separate activity unit. More information on the barcode-visualization tool will be described in the second findings chapter.

Themes that emerged from the coding framework, code counts, and barcode-visualization tool included how often teachers discussed or were observed enacting epistemic agency by drawing on students' funds of knowledge, what challenges they faced in doing so, and how students responded to this kind of instruction in classroom observations. This analysis will be compared with the quantitative analyses described next.

2. Quantitative Analysis

First, to answer my first and third research questions about how often teachers reported enacting epistemic agency and funds of knowledge, I examined descriptive statistics for teacher and student survey questions. I used descriptive statistics to report general trends in the data for all 19 study teachers and their students for both epistemic agency items and funds of knowledge items. These trends identified in the teacher surveys will be reported in the first findings chapter and the trends for student survey findings will be reported in the third findings chapter.

Based on the findings from the descriptive statistical analysis of teacher survey data, I created categories of high, medium, or low for each construct using the standard deviation of the combined average epistemic agency and funds of knowledge scores across study years. For epistemic agency, starting with the lowest score, I used the standard deviation of 0.51 to determine the group cut-offs. The medium group was one standard deviation away from the lowest score and the highest group was two standard deviations away from the lowest score. Anything less than one standard deviation away from the mean was the low group. I carried out the same process for funds of knowledge, which had a standard deviation of 0.46. These categorizations can be seen in Table 11 in the first findings chapter.

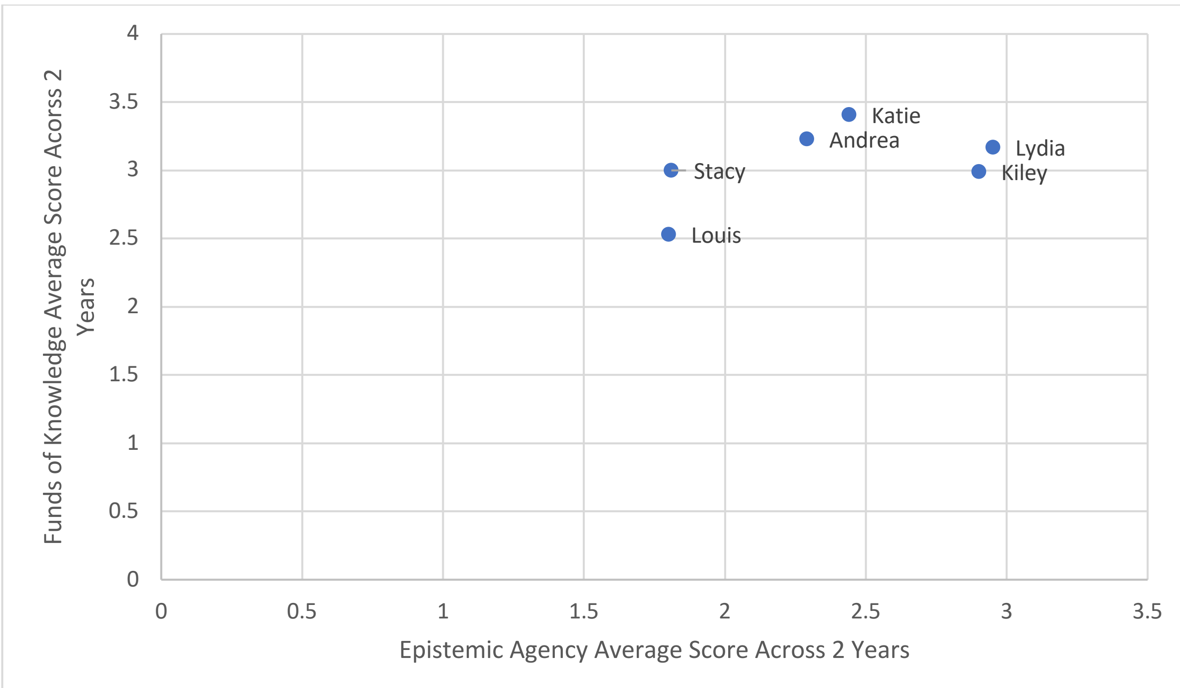
Figure 2 below shows a graph of the six teachers who had the highest combined average epistemic agency and funds of knowledge score for their district as well as the most complete data set; their scores have been graphed as a function of their average for epistemic agency and funds of knowledge. I used the findings from this descriptive statistical analysis to identify these six focal teachers to focus further on in the interviews and observations (as described above), however, I also conducted further statistical tests on their students' responses. To answer my third research question on whether student and teacher reports aligned for each construct, I utilized an analysis of variance (ANOVA) to determine differences between focal teachers and their students for epistemic agency and an unpaired t-test to determine differences between teachers and students for funds of knowledge. These two statistical approaches allowed me to get a general sense of student and teacher agreement or disagreement related to my two constructs of interest.

To elaborate, an ANOVA was conducted to compare the three categories that were previously created of low, medium, and high for epistemic agency. In this analysis, the student responses were compared by grouping focal teachers based on their responses in the teacher survey. As such, the student responses were the quantitative responses while the teacher responses (and whether teachers were high, medium, or low) were the categorical explanatory variable.

For funds of knowledge, I conducted an unpaired t-tests to assess whether there were significant differences between students who had a teacher that rated themselves high or medium. There were no low focal teachers for funds of knowledge. I conducted an unpaired t-test to see if there were any meaningful differences between the student responses from two groups of teachers: one group of teachers who scored themselves high on funds of knowledge and another group who scored themselves medium for funds of knowledge.

Figure 2

Teacher Epistemic Agency and Funds of Knowledge Average Score Comparison



This graph was the basis for the groupings for the ANOVA and the t-test. The ANOVA examined differences in student responses between groups based on whether teachers reported a high, medium, or low average on epistemic agency: Louis and Stacy were grouped as ‘low’, Andrea was grouped as ‘medium’, and Kiley, Katie, and Lydia were grouped as ‘high’ for epistemic agency. A t-test was used for whether teachers scored themselves high or medium on funds of knowledge; there were no teachers who scored low relative to the standard deviation away from the mean and as such an ANOVA was not appropriate since there were two groups instead of three. The t-test examined differences in student responses between groups based on funds of knowledge score. For this test, Louis was ‘medium’ and Kiley, Katie, Stacy, Andrea, and Lydia were grouped as ‘high’ funds of knowledge teachers. An unpaired t-test was chosen because the data were collected from different individuals over different days. The analysis was done in R (R Core Team, 2022).

V. Teacher Survey Findings

This chapter presents findings which answer my first research question: How often did middle school science teachers across the state of California create opportunities for students to (1) activate epistemic agency in engaging with the science and engineering practices and (2) draw on students' funds of knowledge? In other words, how often did teachers report activating student epistemic agency and funds of knowledge? First, using descriptive statistical analysis, I describe how often the 19 teachers in my sample reported activating student epistemic agency across the two study years and highlight whether there were any notable differences among teachers in different districts. Next, I use the same format to present the findings for teachers' reported use of student funds of knowledge. Last, I present findings related to the comparison between the epistemic agency and funds of knowledge findings.

A. Epistemic Agency

1. Reported SEPs Implementation Across Study Years

Since epistemic agency has been operationally defined in this study by how frequently students were doing the SEPs in their science class, I analyzed teacher reports on how frequently they engaged students in each of the SEPs. Table 9 below gives the data for how frequently teachers reported engaging students in these SEPs on average, as well as a combined average for each SEP and the difference across years for each SEP.

Table 9

Teachers' Reported Average SEP Implementation

How often did you have students…	Average Y1	Average Y2	Combined average	Difference across years

Communicate information	2.74	2.79	2.77	0.05
Support claims using evidence	3.00	3.05	2.89	0.05
Construct explanations	2.32	2.42	2.37	0.11
Develop models	2.79	2.79	2.79	0.00
Critique models	1.58	1.79	1.69	0.21
Analyze data	1.94	2.05	2.00	0.11
Interpret data	1.58	2.05	1.82	0.47
Defend claims using reasoning	2.47	2.26	2.37	-0.21
Evaluate scientific explanations	1.94	1.79	1.87	-0.16
Ask scientific questions	2.52	2.32	2.42	-0.21
Plan investigations	1.54	1.56	1.55	0.02
Conduct investigations	3.01	3.15	3.08	0.14

Note. Scores were calculated for these Likert scale items by ascribing a value from 1–4 for each response option, with 1 representing "never," 2 representing "sometimes," 3 representing "often," and 4 representing "all or almost all the time".

This descriptive analysis shows that teachers engaged students in some SEPs more than others. In general, teachers' enactment of students doing the SEPs increased for each SEP more often than decreased; the only SEPs with decreasing averages across study years was defend claims using reasoning, evaluate scientific explanations, and ask scientific questions (develop models had a difference of 0 meaning there was no decrease or increase across years). These three SEPs make up ¼ of the questions asked about students doing the SEPs. This lends more support for the claim that, overall, teachers reported enactment of epistemic agency increased modestly over study years because there was more SEPs with increases across years than decreases.

When looking at the most frequently and least frequently implemented SEPs, there was an interesting distinction between planning and carrying out investigations. Conducting investigations was reported by teachers as the SEP students were doing the most in both study years with a combined average score of more than “often” (*M*=3.08). Interestingly, teachers reported having students plan investigations a little more than “rarely” (with a combined average of 1.55 across both years). Of those SEPs asked about in the survey, students conducting investigations was reported the most and planning investigations the least.

In summary, there were modest overall increases for epistemic agency across all 19 study teachers across years. However, there were some differences in individual SEP implementation with certain SEPs (e.g., conducting investigations) being implemented more often than others (e.g., planning investigations). Next, I will discuss the findings related to specific teachers’ reports about SEP implementation and epistemic agency.

2. General Trends in reported averages across study years

In annual end-of-year surveys, all 19 teachers were asked how frequently the students in their classrooms engaged in the SEPs across the academic schoolyear (e.g., “Thinking about your science instruction over the entire year, how often did you have students develop procedures for a scientific investigation to answer a scientific question?”). The survey items used to operationally define epistemic agency can be found in the Appendix. Response options were given as never or rarely (scored as 1), sometimes (scored as 2), often (3), or all or almost all science lessons (4). Table 8 below is organized by reported average frequency of implementation of student epistemic agency in the first study year, the second study year, and the difference between averages between years.

The top five highest reported frequencies were teachers from extensive, moderate, and no support districts, with the highest average frequency from Jessica in the Glacier district (3.17). The lowest reported averages were from teachers in both moderate and extensive support districts. Kiley from Ravenview, the “no support” district, was in the top five highest averages. As such, there were no consistent patterns between which teachers reported high or low frequency of implementation of epistemic agency in the first study year related to the teachers’ district and level of NGSS support.

I next examined the difference between each teacher’s reported averages for each study year to understand how their instruction changed across the two years. Table 8 below includes data organized by the difference between the reported averages of frequency of implementation in the first year of the study and the second, as well as a combined average for both years and the difference in change between study years. Teachers are organized from lowest to highest combined average epistemic agency score. Figure 3 below Table 8 depicts the differences for each study teacher between years. The black dots represent the average from the first study year and the red dots indicate the average for the second year.

Table 8

Teachers’ Reported Average of Frequency of Engaging Students’ Epistemic Agency

Participant name	District + level of NGSS support	Average EA 18-19 (Y1)	Average EA 19-20 (Y2)	Combined average EA across years (Y2+Y1/2)	Difference between years (Y2-Y1)
Natasha	Glacier, extensive	1.17	1.76	1.44	0.59
Megan	Valley Creek, extensive	1.13	1.71	1.47	0.58
Desiree	Ravenview, none	2.25	1.30	1.57	-0.95
Louis	Kenmore, extensive	1.96	1.71	1.80	-0.25
Stacy	Valley Creek, extensive	2.29	1.60	1.81	0.69

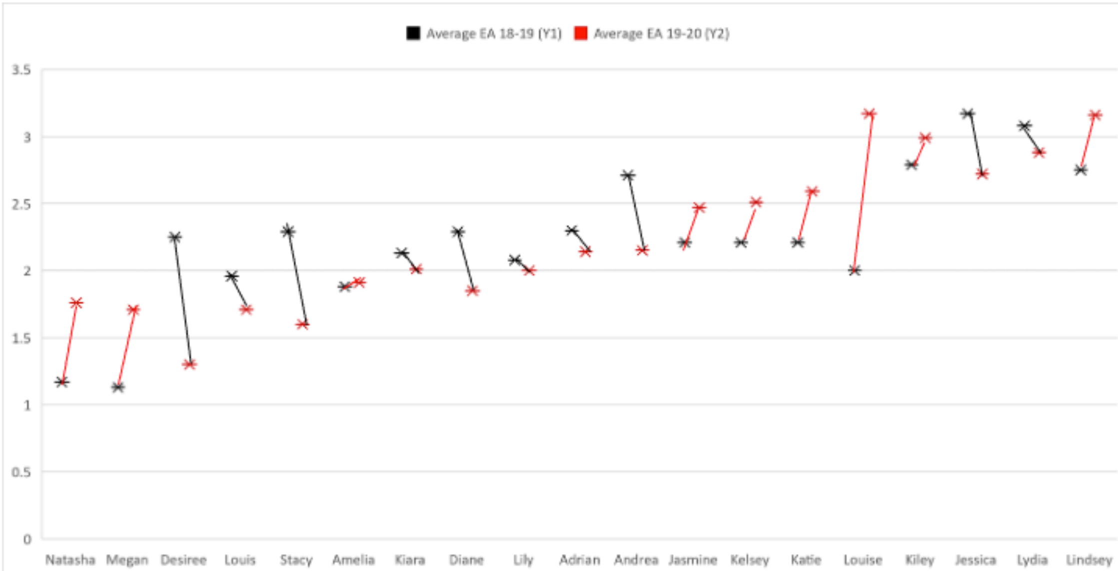
Amelia	Tidewater, extensive	1.88	1.91	1.88	0.04
Kiara	La Paloma, extensive	2.13	2.01	1.98	-0.12
Diane	Tidewater, moderate	2.29	1.85	1.98	-0.44
Lily	Valley Creek, extensive	2.08	2.00	2.03	-0.08
Adrian	Tidewater, moderate	2.30	2.14	2.20	-0.16
Andrea	Glacier, extensive	2.71	2.15	2.29	-0.56
Jasmine	Valley Creek, extensive	2.21	2.47	2.32	0.26
Kelsey	Valley Creek, extensive	2.21	2.51	2.35	0.30
Katie	La Paloma, extensive	2.21	2.59	2.44	0.38
Louise	Glacier, extensive	2.00	3.17	2.71	1.17
Kiley	Ravenview, none	2.79	2.99	2.90	0.2
Jessica	Valley Creek, extensive	3.17	2.72	2.93	-0.45
Lydia	Tidewater, moderate	3.08	2.88	2.95	-0.2
Lindsey	Glacier, extensive	2.75	3.16	2.99	0.41
TOTAL AVERAGES		2.24	2.24	2.21	0.13

Note. Scores were calculated for these Likert scale items by ascribing a value from 1–4 for each response option, with 1 representing "never," 2 representing "sometimes," 3 representing "often," and 4 representing "all or almost all the time".

Figure 3 below shows the change over time between study years for each teacher. A red line between data points indicates an increase over years (meaning their reported score was higher in the second year than the first year) and a black line indicates a decrease over study years (their reported score was higher in the first year than the second year).

Figure 3

Reported Epistemic Agency Implementation Differences Between Years for Each Study Teacher



As seen in Table 8 above, there was a nearly even split between teachers who reported an increased frequency of implementation of student engagement in SEPs in the second year of the study compared to the first. In other words, nine teachers reported *decreases* in students engaging in the SEPs across study years while 10 teachers reported *increases*. Overall, across all 19 teachers, there was a total average increase of 0.13 between study years. Although both the averages for each study year stayed the same (*M*=2.24), the average difference between years across all 19 teachers suggests that there were more cases of teachers increasing implementation of epistemic agency rather than decreasing. Further, the general slope of the line for the second study year is trending upwards. However, these increases were modest, especially compared to funds of knowledge instruction as will be seen later.

There were no consistent patterns between which teachers reported increases or decreases between study years related to the teachers' district and level of NGSS support. The top five teachers with the highest reported increase between study years (Louise, Stacy, Natasha, Megan, and Lindsey) were all from Valley Creek or Glacier school districts, which were extensive support districts. However, there were also teachers from these extensive support districts who reported large average decreases between study years, like Andrea and Jessica, for example. Although Desiree from a no support district in Ravenview reported the largest decrease between study years (-0.95), her counterpart at Ravenview, Kiley, reported an increase between study years (+0.20). Again, there were no consistent patterns in any of the district support groups.

However, there were trends across years that showed that teachers who rated themselves high in the first year reported a decrease in the second year and vice versa. In general, those teachers who reported decreases over the study years reported a comparatively high frequency of implementation in the first year than teachers who reported increases over the study years. For example, on average, Jessica and Andrea reported averages of 3.17 and 2.71, equating to engaging students in the SEPs slightly more or less than often. However, they ended with two of the largest decreases over study years. As another example, Lydia and Jessica had the highest reported averages of implementation in the first year (3.08 and 3.17 respectively) but both decreased in the second year. With the exceptions of Kiley and Lindsey, no teachers who reported increases over study years reported an average higher than 2.21 (slightly more than "sometimes") in the first year. In other words, those teachers who had increases over study years reported a relatively lower frequency of implementation in the first year than those teachers who had decreases over study years. As another example, although Lindsey and Louise had smaller reported averages in the first year compared to Lydia and Jessica, they both ended with higher reported averages in the second year (3.16 and 3.17 respectively). Importantly, the lowest reported average for the 2018-2019 academic year was 1.13, while the lowest for the 2019-2020 academic year was 1.30, again suggesting an overall increase in reported implementation across teachers and across years.

It is important to note that, even when teachers reported decreases, this is not to say that they were never engaging students in the SEPs. In other words, decreases across years did not necessarily mean that teachers were engaging students in the SEPs rarely or never. For example, although Lydia decreased across the two study years, she ended with one of the highest average reported frequencies of implementation across the two years (M= 2.88). In the second study year, Lindsey had the highest average reported frequency (M= 3.16), followed Kiley (M= 2.90) and then Lydia (M= 2.88). This is to say that even at the lower end of implementation, teachers reported still engaging students in the SEPs more than "sometimes."

In summary, descriptive analysis of the data suggests that there was an overall increase of epistemic agency implementation across study years and across teacher participants. However, there did not appear to be consistent patterns regarding teachers' reported combined average and the district they taught in. In the following section, I present findings related to specific teachers' implementation of student funds of knowledge.

B. Funds of Knowledge

In annual end-of-year surveys, teachers were also asked about how frequently they drew on students' funds of knowledge in their instruction by, for example, guiding students to see the connections between students' everyday lives and what is done in science class. The items used for the funds of knowledge analysis can be found in the Appendix. Response options were the same as the ones given for epistemic agency questions. Table 10 below is organized by reported average frequency of implementation of funds of knowledge in both study years, organized by smallest to largest combined funds of knowledge average score.

Table 10

Teachers' Reported Average Frequency of Drawing on Students' Funds of Knowledge

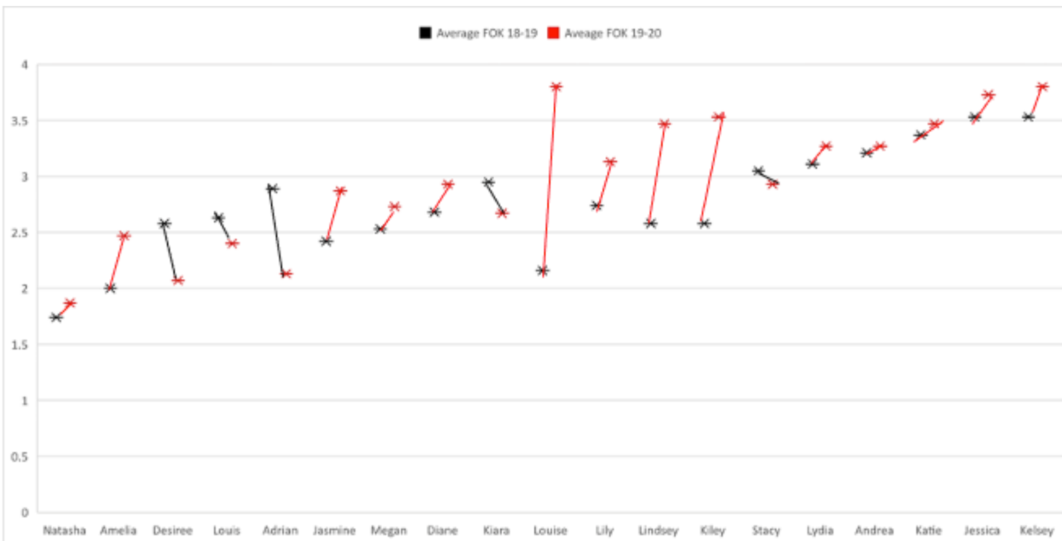
Participant name	District + level of NGSS support	Average FOK 18-19 (Y1)	Average FOK 19-20 (Y2)	Combined average FOK across years (Y2+Y1/2)	Difference between the averages between years (Y2-Y1)
Natasha	Glacier, extensive	1.74	1.87	1.80	0.13
Amelia	Tidewater, moderate	2.00	2.47	2.20	0.47
Desiree	Ravenview, none	2.58	2.07	2.36	-0.51
Louis	Kenmore, extensive	2.63	2.40	2.53	-0.23
Adrian	Tidewater, moderate	2.89	2.13	2.57	-0.76
Jasmine	Valley Creek, intesnive	2.42	2.87	2.61	0.45
Megan	Valley Creek, extensive	2.53	2.73	2.62	0.21
Diane	Tidewater, moderate	2.68	2.93	2.79	0.25
Kiara	La Paloma, extensive	2.95	2.67	2.83	-0.28
Louise	Glacier, extensive	2.16	3.80	2.86	1.64
Lily	Valley Creek, extensive	2.74	3.13	2.91	0.40
Lindsey	Glacier, extensive	2.58	3.47	2.96	0.89
Kiley	Ravenview, none	2.58	3.53	2.99	0.95
Stacy	Valley Creek, extensive	3.05	2.93	3.00	-0.12
Lydia	Tidewater, moderate	3.11	3.27	3.17	0.16
Andrea	Glacier, extensive	3.21	3.27	3.23	0.06
Katie	La Paloma, intesive	3.37	3.47	3.41	0.10
Jessica	Valley Creek, extensive	3.53	3.73	3.62	0.21
Kelsey	Valley Creek, extensive	3.53	3.80	3.64	0.27
TOTAL AVERAGES		2.75	2.98	2.85	0.23

Note. Scores were calculated for these Likert scale items by ascribing a value from 1–4 for each response option, with 1 representing "never," 2 representing "sometimes," 3 representing "often," and 4 representing "all or almost all the time".

Figure 4 below shows the change over time between study years for each teacher. A red line between data points indicates an increase over years (meaning their reported score was higher in the second year than the first year) and a black line indicates a decrease over study years (their reported score was higher in the first year than the second year).

Figure 4

Reported Funds of Knowledge Implementation Differences Between Years for Each Study Teacher



Descriptive analysis of the data in Table 10 show that in general, teachers reported drawing on students' funds of knowledge often and this frequency of implementation increased across all teachers year over year. First, in the second study year, there were nine teachers who reported a frequency of above three (more than often), compared to six teachers who reported a frequency of above three in the first year of the study. Second, there was also a combined average increase of 0.23 (nearly 25%) in implementation between years. Further, only five of the 19 teachers reported decreases in implementation between the first and second years of the study (Stacy, Kiara, Adrian, Louis, and Desiree). Finally, seven of the 19 teachers reported a score of 3.00 or higher; ten teachers reported a score of

2.91 or higher. Taken together, these findings indicate that overall, teachers were increasingly drawing on students' funds of knowledge in their science lessons year over year.

However, like the findings for epistemic agency, there were no consistent patterns in whether a teacher reported an increase or decrease over study years based on their districts' level of NGSS support. Teachers with the top five highest growth between study years (Louise, Kiley, Lindsey, Amelia, and Jasmine) were from districts representing extensive, moderate, and no support. The same finding held for the top five largest decreases across study years: Stacy, Louis, Kiara, Desiree, and Adrian had the largest decreases across study years and represented districts that were extensive, moderate, and no support. There was no consistent pattern between which district teachers taught in and their reported increased or decreased implementation of student funds of knowledge between study years.

There was an overall increase in the frequency of funds of knowledge implementation, as will be discussed further below. The top five teachers with the highest reported frequency of implementation came from either extensive or no support districts (Kelsey, Louise, Jessica, and Katie from extensive support districts and Kiley from a no support district). Two teachers from the moderate support district had two of the top five lowest reported implementation averages (Adrian and Amelia). Again, there were no consistent patterns between teachers' reported implementation and the district they taught in.

When examining differences between teachers across years, there were some teachers who had larger increases or decreases between study years than others. For example, Adrian started with an average in the middle of the group in the first year of the study but ended with the lowest frequency of implementation in the second year, leading to the largest decrease over study years (-0.76). However, again, it is important to note that a decrease between study years does not necessarily mean that teachers were drawing on students' funds of knowledge rarely or never. For example, although Stacy decreased across the two study years, she ended with a relatively average frequency of implementation across the two years (*M*=2.93) that placed her in the middle of the sample in the second study year. She had one of the highest reported frequencies of implementation in the first study year (*M*= 3.05) and only decreased slightly to an average of 2.93. This suggests she was still using students' funds of knowledge often in the first year and almost often in the second year.

In summary, teachers reported a combined average score across both study years of 2.85, meaning they reported doing this nearly "often." Findings indicate that teachers were increasingly using students' funds of knowledge in their instruction, although there were no consistent patterns in how frequently teachers reported drawing on students' funds based on teachers' district. Next, I will compare the epistemic agency and funds of knowledge survey analyses.

C. Comparisons Between Epistemic Agency and Funds of Knowledge Responses

In this section, I describe comparisons between the average scores for epistemic agency and funds of knowledge among the 19 teacher sample. Table 11 below includes the combined average scores across the two study years for each teacher and is organized by smallest to largest epistemic agency score. Epistemic agency was chosen as the organizing variable because it is the construct of interest and funds of knowledge is the tool which teachers use to enact epistemic agency. A description of comparisons between these data follows Table 11.

I created categories of high, medium, or low for each construct using the standard deviation of the combined average epistemic agency score across study years. For epistemic agency, starting with the lowest score, I used the standard deviation of 0.51 to determine the group cut-offs. The medium group was one standard deviation away from the lowest score and the highest group was two standard deviations away from the lowest score. Anything less than one standard deviation away from the mean was the low group. I carried out the same process for funds of knowledge, which had a standard deviation of 0.46. These categorizations can be seen in Table 11 below.

Table 11

Combined Average Scores for Epistemic Agency and Funds of Knowledge

Participant name	District + level of support	Combined EA average across years	EA categorization	Combined funds of knowledge average across years	FOK categorization	Combined EA and FOK average
Natasha	Glacier, extensive	1.44	Low	1.80	Low	1.71
Megan	Valley Creek, extensive	1.47	Low	2.62	Medium	2.46
Desiree	Ravenview, none	1.57	Low	2.36	Medium	2.56
Louis	**Kenmore, extensive**	**1.80**	**Low**	**2.53**	**Medium**	**2.60**
Stacy	**Valley Creek, extensive**	**1.81**	**Low**	**3.00**	**High**	**3.02**
Amelia	Tidewater, moderate	1.88	Low	2.20	Low	1.99
Kiara	La Paloma, extensive	1.98	Medium	2.83	High	2.91
Diane	Tidewater, moderate	1.98	Medium	2.79	High	2.67

Lily	Valley Creek, extensive	2.03	Medium	2.96	High	2.71
Adrian	Tidewater, moderate	2.20	Medium	2.57	Medium	2.87
Andrea	**Glacier, extensive**	**2.29**	**Medium**	**3.23**	**High**	**3.19**
Jasmine	Valley Creek, extensive	2.32	High	2.61	Medium	2.41
Kelsey+	Valley Creek, extensive	2.35	High	3.64	High	3.46
Katie	**La Paloma, extensive**	**2.44**	**High**	**3.41**	**High**	**3.31**
Louise	Glacier, extensive	2.71	High	2.86	High	2.15
Kiley	**Ravenview, none**	**2.90**	**High**	**2.99**	**High**	**2.59**
Jessica^	Valley Creek, extensive	2.93	High	3.62	High	3.51
Lydia	**Tidewater, moderate**	**2.95**	**High**	**3.17**	**High**	**3.10**
Lindsey	Glacier, extensive	2.99	High	2.96	High	2.59

Note: Scores were calculated for these Likert scale items by ascribing a value from 1–4 for each question, with 1 representing “never” and 4 representing “all or almost all the time”. ^Missing student survey data for the 2018-2019 school year. +Missing observation notes for the Spring 2019 semester.

In general, teachers had higher funds of knowledge averages than epistemic agency averages. The highest average was 3.64 for funds of knowledge while the highest average for epistemic agency was 2.99. None of the teachers reported an average of three or greater for epistemic agency, while six teachers reported an average of three or greater for funds of knowledge. The smallest reported average for funds of knowledge (M= 1.80) was also 0.16 points higher than the smallest reported average for epistemic agency.

Again, there were no consistent patterns between teachers of different districts, but there were some differences between teachers within the same district. Within the Glacier (extensive support) district, Natasha was lower compared to other Glacier teachers for both epistemic and funds of knowledge. Louise had the highest amount of growth between the two study years for both epistemic agency and funds of knowledge. Within the La Paloma (extensive support) district, Katie consistently reported higher averages for both agency and funds when compared to Kiara. For Valley Creek (extensive support), Stacy and Jessica reported the highest averages between the two constructs. Of the Tidewater (moderate support) teachers, Lydia scored higher for funds and agency, except for Amelia who reported growth for epistemic agency between study years when Lydia did not. Finally, among Ravenview (no support) school district teachers, Kiley reported higher averages than Desiree on both epistemic agency and funds of knowledge.

When looking at the high, medium, and low categorizations for each construct, importantly, all teachers who scored high for epistemic agency also scored high for funds of knowledge (except for Jasmine who was in the medium group for funds of knowledge). The reverse was not necessarily true for the low epistemic agency scores; in other words, if a teacher scored low on epistemic agency, they could be considered high, medium, or low for funds of knowledge.

In summary, teachers overall scored higher for funds of knowledge than epistemic agency. However, those teachers who scored high for epistemic agency scored high for funds of knowledge, with one exception (Jasmine). Those who scored low on epistemic agency could score high, medium, or low on funds of knowledge. This suggests that when teachers were frequently implementing epistemic agency, they were also frequently implementing funds of knowledge. However, when teachers were not frequently implementing epistemic agency, they could be frequently implementing funds of knowledge. To better understand the relationship between these two constructs, further analysis was done with the teacher interviews and classroom observations.

To identify teachers to further examine using interview and observation data, I first created a combined average score from each teachers' average epistemic agency and funds of knowledge score. This is the "combined EA and FOK average" column in Table 11 above. I chose the teacher in each district with the highest combined average and the most complete data set with one exception. Although Jessica was the teacher with the highest combined average score in the Valley Creek district, she was missing student survey data. In this case, I went with the next highest teacher, which was Stacy. The teachers bolded in Table 11 will be further discussed in the next chapter.

VI. Teacher Interview and Observation Findings

In this chapter, I present findings from the observation analysis and the analysis of the interviews before, during, and after the classroom observations. These findings address the second research question: What opportunities did teachers discuss and enact to engage student epistemic agency by drawing on students' funds of knowledge? As stated earlier, I analyzed all the observations from each study year and the accompanying interviews for the six focal teachers with the highest cumulative survey score for epistemic agency and funds of knowledge. These teachers were Andrea (Glacier), Louis (Kenmore), Katie (La Paloma), Stacy (Valley Creek), Lydia (Tidewater), and Kiley (Ravenview).

Interviews and observations were coded according to the coding framework in Table 6 in the methods chapter. My research partner and I first coded all interviews and observations for any mention of *intellectual work of figuring out*. This was any mention or observation of students doing one of the SEPs. I then took all the references that were coded as *intellectual work of figuring out* and coded for the second cycle of codes: *teacher doing*, *student doin*g, or *teacher guided*. *Teacher doing* was any instance where teachers were either doing or talking about doing the intellectual work either for students or instead of students. This might look like a teacher giving a demonstration during a whole-class presentation. *Student doing* was used any time that the students were doing the figuring out for one or more SEPs. This might look like students engaging in a debate while the teacher listens, students asking for materials that they have identified as necessary for an investigation, or students sharing their initial ideas on a phenomenon. This had to be activity that was student generated but could occur in the context of an overall teacher directed lesson (e.g., teacher decides the content of the investigation, but students identify the materials needed). Finally, *teacher* *guiding* was any instance where teachers and students were engaged in the intellectual work of figuring out together; for example, a student asks a question that the teacher does not know the answer to, and they work together to find an answer or the teacher scaffolds a discussion with open-ended questions for students to answer. There was also a code for *anti-guiding the intellectual work of figuring out*. This was any instance where teachers mentioned or were observed limiting students' opportunities to enact epistemic agency; this might look like a teacher giving students step-by-step lab instructions. Finally, while I was coding for the cycle two epistemic agency codes, I also coded these references for the funds of knowledge codes that can be found in Table 7 in the methods chapter. When there was activity happening in the classroom that had been identified *as intellectual work of figuring out*, I was interested to know what kind, if any, funds of knowledge were being discussed or leveraged.

Once these references were coded for the second cycle epistemic agency codes and funds of knowledge codes, I used Atlas.ti to generate code occurrence reports to understand how frequently the different codes were identified in the data. Then, since code frequency counts are most useful for exploratory analyses of qualitative data and not necessarily accurate indicators of what the data are really saying, I chose the top two teachers who had the most instances of *student doing* activity. I then took the observations for these two teachers and created barcode-like graphics (which will be further explained below) to better visualize and understand the dynamic exchange of epistemic agency between teachers and students throughout a single class period. These visuals also include indications of when a fund of knowledge was mentioned or leveraged in instruction.

Below, I present findings from the six focal teachers' interviews and observations related to epistemic agency. These findings highlight themes that arose across the six focal teachers' interviews and observations in all three semesters included in this study. Then, I present findings from interviews and observations regarding both epistemic agency and funds of knowledge. Finally, I conclude with the two case studies of teachers who were exemplary. I present detailed findings about these two exemplary teachers for each of the three observations that were conducted in Fall 2018, Spring 2019, and Fall 2019 and the interviews accompanying these observations. These case studies highlight how activity was dynamic and constantly in flux during the span of a given class period.

A. Findings Across the Focal Teacher Sample: Epistemic Agency

First, I present findings related to the code occurrence analyses for the three Cycle 2 codes (e.g., *teacher doing, student doing*, and *teacher guided*) across the six focal teachers' interviews and observations. I present findings from the three codes in order from the most frequent code to the least frequent code. *Teacher guiding* was the most frequently observed code, followed by *teacher doing*, *student doing*, and lastly, *anti-guiding*.

1. Teacher guiding activity findings

There were many instances in the data of teachers guiding instruction, such that students and teachers were working together. Indeed, there were 201 instances of teachers guiding instruction across the six focal teachers. Katie had 50 instances, Stacy had 49, Louis had 39, Andrea had 31, Lydia had 18, and Kiley had 14.

As an example from observations, during Louis' Fall 2019 observation, students frequently generated their own questions during whole class discussions and Louis provided space for other students to answer their peers' questions. To elaborate, Louis explained that the lesson for the day was about genetics and most of the activity would be notetaking from a video. Louis admitted to students that this would be a mostly teacher directed day because "scientists need this in real life too. They need a lot of information before they can go on and do investigations and make discoveries." After the video was displayed for the class, this exchange ensued:

> Student A: What does food have to do with genetics?
>
> Louis: Oh, I love that question. Does someone want to answer her?
>
> Student B: Corn is a plant. Plants have genes and they get traits from their parents as well.

In the above excerpt, a student generated their own question about why food is relevant to genetics and Louis not only validated the question but gave space for another student to volunteer their knowledge to answer the question. Although the overall activity that students were engaged in was *teacher doing* (since the teacher chose the video students would watch), Student A had the opportunity to generate their own question ("What does food have to do with genetics?"), the teacher validated this question as worthy of further inquiry, and opened the floor for another student to answer. Student B was then able to use their everyday knowledge about corn as a plant and their prior content knowledge about plants having genes and traits to answer their peer.

As an example in interviews, Stacy described a strategy that she used with students to intentionally guide them in their own exploration or investigation. In her Fall 2019 post-observation interview, Stacy said:

> I was trying to get them to explore something, and it wasn't working, and so I paused and I was like, "I'm going to tell you something." I think it was current, like electric

> currents. I was like, "When there is an electric current running through a wire, it creates a magnetic field. Scientific fact. This happens. Prove it." So, I think that part [was] when I left it more open-ended for them to figure out. Instead of saying, "We have this, we have this, now what?", saying, "Okay. Here's this, here's this. What do you think is happening here?"

It is important to note that Stacy likely meant "prove it" in a colloquial sense when talking with the interviewer and that scientists do not actually prove facts. However, in this example, Stacy described her intentional thought process that preceded her decision to go about the lesson in a different way than she planned. Stacy went on to explain how this move changed the way that students engaged with an investigation:

> And they were like, "Look, Miss Soto. I moved the magnet with my wire." And I was like, "So what does that mean?" And so when I reversed it like that, all of a sudden, they were kind of exploring a little bit differently. I found it to be an effective strategy because they're really comfortable with claim, evidence, reasoning.

In this example, Stacy leveraged a *teacher doing* pedagogical move (giving students information) to support their *student doing* activity (investigation with a magnet and wire). Further, she drew on students' funds of knowledge by leveraging their prior content knowledge (claim, evidence, reasoning) to re-format the investigation in such a way that changed students' investigation of the magnet and wire. This finding suggests that *teacher doing* activity can be used by teachers intentionally and skillfully to guide students in doing their own exploration. Therefore, as will be discussed further below, I caution against assumptions or interpretations that when teachers do this kind of intellectual work, that students are *not* able to do the intellectual work of figuring out. Rather, teachers like Stacy showed exemplary skill in knowing when and how to “do the work” in such a way that opened up space for students to participate in the figuring out happening in class (e.g., investigating with the magnet and wire differently when Stacy provided a little additional information). In fact, as will be described below, teachers described some challenges with *student doing* activity that made *teacher doing* activity necessary.

2. Teacher doing activity findings

Across the interviews and observations, there were a total of 160 instances of *teacher doing* activity across the six focal teachers. Of these, Stacy had 52 instances, Lydia had 34, Louis had 22, Kiley had 20, Katie had 19, and Andrea had 13. As was described earlier, this kind of *teacher doing* was not seen in the data as frequently as *teacher guiding* instruction, but it was seen more frequently than *student doing* activity.

As an example of what *teacher doing* activity looked like in the observations, I briefly describe an excerpt from Louis’ Fall 2018 observation. In this lesson, Louis read a procedure for an investigation on mixing different substances from a book to help students determine whether new substances could be created through mixing. Louis read aloud to students what materials they would need, how much of each material they would need, what students would be doing with the materials, and who was allowed to walk to the front of the classroom to collect materials for their group. Louis’ approach did not open space for students to determine what materials were needed or to play with mixing the different substances on their own. Further, besides the substances being familiar to students outside of the classroom (e.g., water), there were no discernible funds of knowledge being leveraged.

As an example of how teachers described *teacher doing* in interviews, Lydia taught a lesson wherein students needed to be chemists to figure out why a water sample brought in by a local farmer was a red color. Lydia explained that the local community was predominantly agricultural so she thought that this would be relevant context for students (this was coded as a local community fund of knowledge). This activity involved students making observations about the substance in the jar and how the substance changed when it interacted with different chemicals. Lydia explained that during these observations,

> I would've liked for them to do a little bit more scientific note taking but I mean just staring at a new chemical… I don't think they're quite trained in how to make observations like an actual chemist would because most of them were just writing, "It's a liquid. It is white."

Lydia went on to say that there were some students who went beyond talking about bubbles or changes in consistency but that, in hindsight, she thought the lesson "just required some direct instruction and *then* some time to apply that instruction."

This was a common concern noted by teachers in interviews. They struggled with wanting students to engage in the SEPs themselves but were not sure when or how to offer the direct instruction students needed. As Lydia explained, students needed direct instruction to support their learning. Teachers did not feel they had the resources available to them, though, to know how to provide this support in a way that they thought was still in the spirit of NGSS and reform-oriented science education. For example, Stacy said, "When [students] are just trying to figure it out, I'm not sure I have a good way to support that." Teachers like Andrea attributed this challenge to calls put forth in the NGSS to engage students in the SEPs; she said that her teaching team and she felt that when they were giving direct instruction, this type of learning was not in the spirit of NGSS, but that students needed the direct instruction to learn the SEPs. Andrea explained that her teaching team and she "found that when we tried to do NGSS, like do it the right way, where [students] look at the microscopes first and take observations, students just had no idea what they were looking at." It is interesting to note that Andrea said that when she gave students direct instruction first, without having the opportunity to explore first, she thought she was not doing NGSS "the right way." The data reveal that teachers struggled with reconciling calls put forth in reform-oriented science education documents to have students do the SEPs with the reality that they thought that students required some direct instruction upfront. However, this is not to say that *student doing* was not observed in observations or discussed by teachers in interviews. As will be discussed below, there were still rich examples in the data of students engaging in the SEPs and examples of activity that grew out of students' funds of knowledge.

3. Student doing findings

I found *student doing* activity to be the least common type of activity implemented in the focal teachers' lessons and interviews. *Student doing* activity was coded 147 times. Stacy had 61 of these instances, Katie had 31, Louis had 23, Lydia had 20, Andrea had 10, and Kiley had 2. Although Stacy had the most *teacher doing* activity, she also had the most *student doing* activity despite frequently saying in her interviews that she thought her instruction was "too teacher directed" (again, a struggle she faced with thinking that she was not doing NGSS if she was doing direct instruction). Below, I will describe what *student doing* looked like in observations and how it was described in interviews.

As an example of *student doing* in observations, Andrea's students were observed conducting their own investigation with a two-way mirror. Andrea explained that there was a popular meme from a movie starring Mr. Bean that her students liked; she described a scene where Mr. Bean is in an interrogation room "doing all kinds of silly things because he thinks he's seeing a mirror. But the detectives in the other room can see him." Andrea took this idea of a two-way mirror (from a fund of knowledge that was coded as pop culture) and had students play with lights, mirrors, and boxes to figure out how the two-way mirror works. During their investigation, students made observations about what they noticed and then came back together as a whole class to develop a class model that explained the two-way mirror phenomenon. The observer made this note during the students' investigation:

> *The students at the table next to me decide to split up: one student stands on one side of the box flashing a light and the other student stands at some distance on the other side of the box. They determine one student will flash the light, the other student will say aloud their observations. The last two group members are writing down the students' observations. The one female student is flashing a light at the 2-way mirror out of the box from either side and asking the group if they can see through it from the other side. The second student standing on the other side of the box says out loud what she can see. The two students taking notes ask clarifying questions ("How bright is it?").*

In this excerpt, students were given the agency to play with the materials that they were given in a way that made sense to them and decide on the process of investigation. Andrea set students up with materials and had them work in small groups to determine how to use the materials and how to divide the work to figure out how the two-way mirror worked. This was coded as *student doing* because students were given space to explore with the materials on their own and design their investigation in collaboration with their peers.

In their interviews, all teachers expressed a desire for students to engage in activities aligned with the SEPs. Stacy explained her reasoning as to why she believed it was important for students to be supported in doing their own activity, saying, “They don't think they can be scientists at this point, not most of them anyways. And so, if we can show them, like you can do what scientists do, then it can push them to that as well.” In general, the six teachers included in this analysis demonstrated an understanding of and desire to enact *student doing* activity to support students’ science learning and self-efficacy.

However, there were also reflections in teacher interviews about why engaging in student-directed activity was challenging. In interviews, teachers also discussed challenges associated with enacting student epistemic agency. These challenges included that students need help with time management to complete assignments, that students need time and scaffolding to be able to do the intellectual work (as mentioned earlier), and that testing limits the amount of curriculum or content that can be covered.

Some teachers also discussed how they struggled with enacting epistemic agency because that meant that students were doing the cognitive work. Teachers were thus tasked with guiding students through the epistemologies of science, helping them to figure out the how and why of science. Kiley explained that “when students get to make their own decisions, dealing with the chaos… it can be a lot.” This quote exemplifies why some teachers struggled with supporting students’ epistemic agency. When many students became the directors of activity as opposed to the teacher, the classroom might feel chaotic. Teachers became responsible for not only helping students to carry out investigations or develop a model (activities that required a great deal of teacher planning and preparation), but also to support students in uncovering the processes undergirding these activities.

Furthermore, teachers discussed limitations they faced related to *student doing* activity and the NGSS curriculum. The lack of NGSS-aligned curriculum available to teachers at the time of the study was mentioned in at least one interview across all six teachers. Katie discussed how she drew on curriculum that her peers were using because she thought that the content "must be interesting and appropriate for my students because it was tested by another teacher with a similar age group." Not having NGSS-aligned curriculum materials meant that teachers' time was constrained because they needed to be both teacher *and* curriculum developer. Teachers utilized whatever curriculum they could find.

4. Anti-guiding instruction findings

There were only 12 instances of *anti-guiding* instruction. Lydia had 1, Katie had 1, Andrea had 10. Stacy, Louis, and Kylie all had no instances. As an example, I present an exchange between Andrea and one student that reveals how teachers wielded power in the classroom to determine what questions were considered appropriate or legitimate. As will be discussed later, it is important for teachers to recognize this power to avoid potentially de-legitimizing examples such as this one. The discussion began with a video about how atoms form.

Andrea: Please copy this one down. "Group 1 and 2 elements tend to give up electrons whereas Groups 16 and 17 want to gain electrons; atoms can either share electrons or take/give them up."

Andrea is quoting the video and asking students to write down this quote. Students are quiet as they copy down notes from the overhead. After the video finishes, Andrea resumes speaking.

Andrea: Why are these elements doing what they are doing? What is this related to? So first video. Ryan, sit down. First video is about gallium. Can someone tell me what atomic number gallium is?

Student A: 31.

Andrea: Yes 31. Gallium is under aluminum which is 13.

Student B: How long is it?

Andrea: Aaron, does it matter?

In this excerpt, Andrea outright rejected a student's question. The student asked how long Gallium is and she responded, "Does it matter?" In her pre-interview, Andrea discussed that she anticipated that students were going to struggle with visualizing atoms because she felt they were too abstract for their grade level. This is interesting to note because the student's question was about struggling to visualize Gallium ("How long is it?"). If Andrea predicted that students would struggle with visualizing atoms, then this seemed like a natural question to ask given the teacher's concerns. However, she was reflective about this in her post-observation interview: She acknowledged that her lesson was predominantly teacher-driven but attributed this to NGSS introducing content on atoms too early.

In summary, there was a range of instruction that was observed in the classroom and discussed in interviews, with teachers *guiding* more frequently than they were doing and teachers doing more than students were doing. There were even fewer instances of *anti-guiding the intellectual work*. In the next section, I will describe how teachers drew on students' funds of knowledge when they were *guiding the intellectual work* or when students were doing the work.

B. Findings Across the Focal Teacher Sample: Epistemic Agency and Funds of Knowledge

In this section, I present findings related to the types of funds of knowledge teachers drew on when the SEPs were also present (whether the activity was *student doing* or *teacher guiding only*). Teachers utilized several different kinds of funds of knowledge in each of these scenarios. Table 12 below gives the number of times each fund of knowledge was mentioned or observed in either *guided* or *student doing* work.

Table 12

Code Co-Occurrence for Guiding Intellectual Work and Student Doing Codes and Funds of Knowledge Codes

	Guiding Intellectual Work	I	O	Student Doing	I	O	Totals
Socioscientific issues	21	15	6	13	11	2	34
Prior content knowledge	17	10	7	13	9	4	30
Community or local geography	20	13	7	7	4	3	27
Personal interests	12	7	5	10	7	3	22
Everyday science examples or experiences	10	7	3	5	3	2	15
Other/non-specific	5	5	0	4	4	0	9
Home/family life	5	1	4	2	0	2	7
Pop culture	2	1	1	4	3	1	6
Language/linguistic resources	3	2	1	1	1	0	4
Totals	95	61	34	59	42	17	154

Note. "I" stands for interviews and "O" stands for observations.

There were more examples of teachers using student funds when they were guiding instruction than when students were doing their own activity. This makes sense because there were more *guiding* instances than *student doing* instances observed. Furthermore, there were more instances of any funds mentioned in interviews than were observed in observations. The three most identified funds were socioscientific issues, prior content knowledge, and community or local geography. The least identified funds were language or linguistic resources, pop culture, and home or family life. In the following sections, I discuss what *guided* or *student doing* instruction looked like when teachers used the three most mentioned funds.

1. Socioscientific issues

The most frequently mentioned or observed fund of knowledge was socioscientific issues, which includes social or global issues as well as geography or the environment that is not local. In other words, teachers frequently drew on students' knowledge about socioscientific issues for the context of their lessons. Socioscientific issues are environmental justice issues that can be embedded within the local context of the community. For example, climate change was the most frequently mentioned socioscientific issue that teachers used as the basis for their lessons. Other socioscientific issues included genetically modified organisms.

In her pre-observation interview from Spring 2019, for example, Stacy mentioned that the larger unit she was teaching was about climate change, but that the lesson that researchers would observe was about flat earth theory. When giving context for the lesson that researchers would observe, Stacy explained that, in a prior lesson, students were doing claim, evidence, reasoning using climate change, which is a socioscientific issue. She explained that she had students write out claim, evidence, reasoning statements to develop their understanding of the scientific consensus on climate change. In this way, Stacy engaged students in an SEP (engaging in argument from evidence) by using a socioscientific. She explained her reasoning for doing this saying,

> It's teaching them to be critical of the information that's out there and to search for their own scientific evidence. That's been a big push for us this year of making

> scientifically literate students, so that when something like climate change deniers…. They would be very well prepared to explain evidence that climate change exists, and it is happening, because that's what we did in our unit.

In this example, she explained how she used climate change in this lesson as a concern that motivated students to argue with their own evidence. Stacy later described how students were engaged to generate their own arguments by talking about local waterways they had seen that were impacted or information they had heard on the news. She went on to state that this phenomenon was intentionally used to “hook” students in such a way that guided them in developing their scientific literacy and argumentative skills. In this way, Stacy taught students to craft an argument against climate change deniers.

2. Prior content knowledge

The second most frequently identified fund of knowledge was prior content knowledge. Prior content knowledge was defined as student knowledge gained from earlier in the same course or previous courses, but it needed to extend further back than the unit or lesson that students were currently engaged in (i.e., prior content knowledge was not coded if students were drawing on prior knowledge from within the same lesson or unit).

As an example, Kiley led a lesson on the reintroduction of wolves in Yellowstone in Spring 2019. She showed a short video that explained the history of wolves in the western region of the U.S., and how they became endangered in the first place because the ranchers killed them due to hunting their livestock. Kiley periodically paused the video to lead a whole class discussion on parts of the video. An excerpt from the researcher’s observation notes highlights how Kiley encouraged students to think back to other lessons where they had seen GPS trackers put on animals for scientific purposes:

> *[The video] shows people shooting the wolves from a helicopter and many of the students start moaning about how that is mean, so the teacher stops the video and explains that it's a tranquilizer gun and they're doing this to put GPS trackers on them to see data on where they're going. Teacher reminds students of other things they have studied that use trackers like this and one student says*, "It's like the butterflies, where they looked at their migration" *and the teacher says*, "Good catch, the wolves aren't really migrating even though I said that, they're just looking at where they are moving," *A student says*, "How are they tracking them…. Is it radio or satellite?" *and the teacher says that she isn't sure, the video doesn't really talk much about this specifically*.

In this exchange, two separate students supply prior knowledge about butterfly migration and GPS trackers and whether the trackers used radio or satellite. Kiley prompted this connection by encouraging students to think back on other content knowledge they might have that could help them to understand what was happening in the video. Further, when one student supplied a response about the wolves that was not technically correct because she used the word "migration," Kiley was quick to respond and admit that she too used the word migration to refer to the wolves' movement patterns.

3. Community or Local Geography

The next most mentioned fund of knowledge was community or local geography. This code was used whenever local sites like libraries, community centers, or museums were mentioned, as well as geographic or environmental concerns that were local to the community.

In her Fall 2018 post-observation interview, when she was asked about the context for the lesson that researchers were going to be observing, Katie discussed how she made a global issue locally relevant to students within the larger unit for the class. Katie explained that in their English class, her students were reading a book called *Long Walk to Water* that she noticed that "they've really connected to. Because the kid that's in that book is 11 years old. They're 11 years old, and so they're connecting because it's a kid their age, that doesn't get to go to school. They walk to and from, five miles a day or more, carrying water." Katie went on to explain that students were interested in talking about how to get people around the world access to water. She capitalized on students' interest in this global issue to introduce them to a locally relevant issue: "In three or so years, they're going to start limiting our water intake here to 55 gallons a day per person at your household. So, I had everybody bring in water and there was 55 gallons back there, so they could see what 55 gallons looks like." Students were then engaged in an engineering design task that helped to minimize water use. In this observation, students worked in small teams to design solutions for their day-to-day life that would help them to keep their water intake to less than 55 gallons a day. In this way, Katie made a locally relevant issue the basis for an engineering design task in which students needed to design their own solutions.

While this section gave singular examples of how teachers mentioned or drew on students' funds of knowledge to encourage epistemic agency, there is more to be learned by taking a closer look at two of the strong teacher examples that emerged from the data. In the next section, I highlight two teachers and what their instruction looked like regarding epistemic agency and funds of knowledge across three semesters. To select these teachers, I chose the two teachers who had the most of each of the three codes: *teacher guiding*, *student doing*, and *teacher doing*. These two top teachers were Katie and Stacy.

C. Case Study Examples

The following sections provide two case studies of teachers who enacted student epistemic agency by drawing on student funds of knowledge. Findings for these case studies utilized an adapted barcode tool to visualize and understand the dynamic exchange of epistemic agency between teachers and students throughout a single class period. To do this, I compiled classroom observation analysis and synthesized it into boxes to create visual displays of case study teachers' instruction over the course of the study. I adopted a data visualization tool meant to reveal patterns in whole-class discussions (Colley & Windschitl, 2020). This tool captures the dynamic interplay between students and teachers during whole-class discussions much like transcripts do, but more effectively distills these data into a barcode-like visual that is more easily interpretable for readers and researchers. I adapted the tool to look at activity throughout a class period and not only whole-class discussion.

I adopted and slightly modified this tool to synthesize case study teacher observation data. This allowed me to more easily highlight differences between cases in the concepts of focus for this study: epistemic agency and funds of knowledge. Each box is an activity unit. An activity unit was defined by the beginning and ending of an activity happening in class; for example, watching a video from beginning to end was one activity unit, student discussion about the video was a separate activity unit, and filling out a worksheet after the discussion was a separate activity unit. The shaded boxes indicate the presence of a code during instruction: a shaded box under the *teacher doing* column means that the teacher was doing the intellectual work alone and when students were doing the work, *student doing* is shaded. When all three columns are shaded at the same time, this indicates an instance of *guiding intellectual work* in the codebook; this was when teacher and student(s) were doing the work together in an activity that was guided by the teachers. The length of these observations changed depending on how many activity units were identified in a lesson. For example, the class time might be the same, but if there were more activity units, the number of shaded boxes is longer down the column. There are timestamps included to indicate the length of the activity unit and overall lesson. The asterisks indicate any time a fund of knowledge as used. The numbers indicate a noteworthy moment and correspond to presentation of this moment in the findings section below. Finally, the performance expectation for each of the observed lessons is included at the top of the box to give an idea of what the lesson was about.

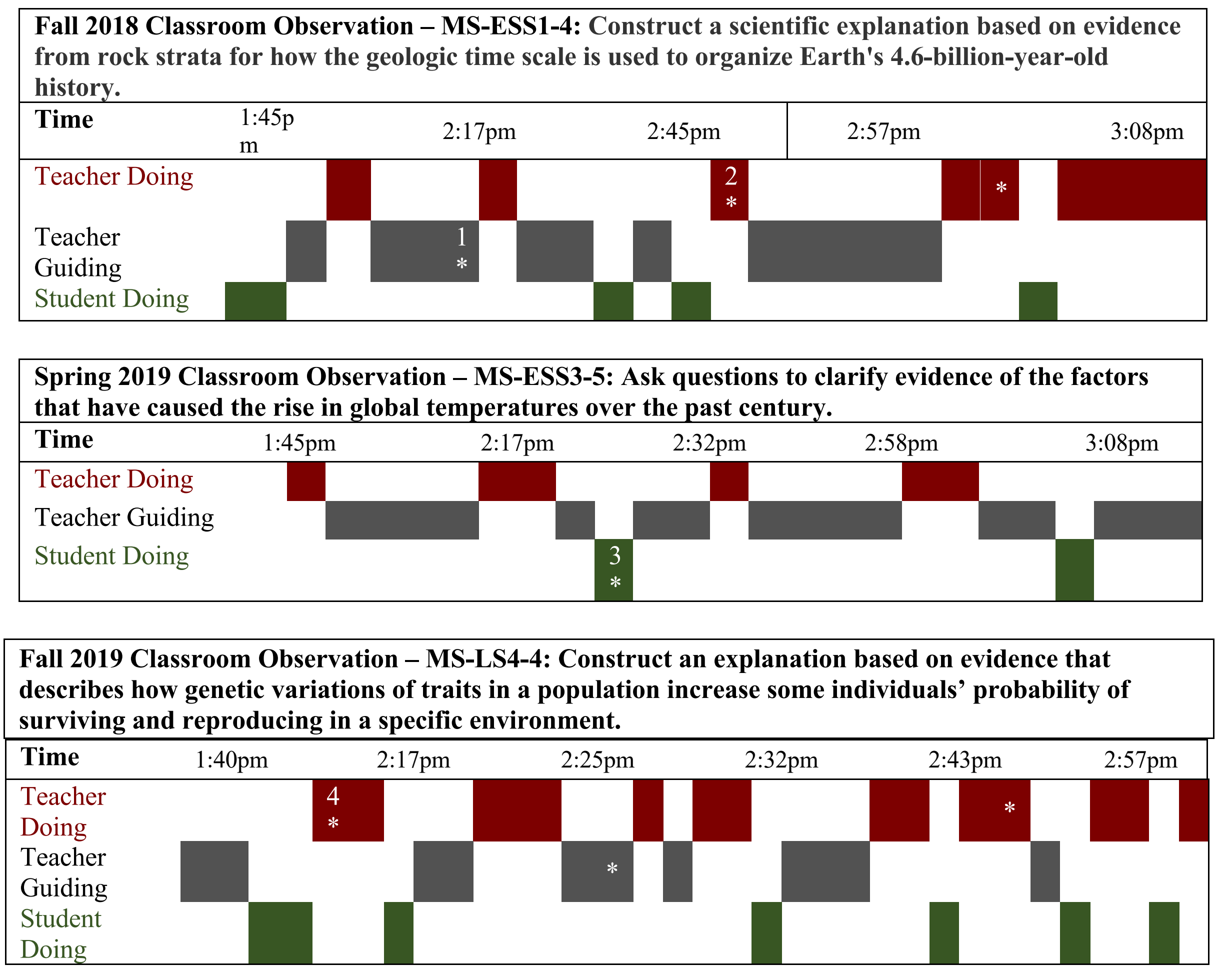
1. Case Study #1: Stacy Soto from Valley Creek

In her survey, Stacy self-reported engaging students in the SEPs across the three study years a little more often than “sometimes” (once or twice a month), with a decline year over year across the study years. However, these self-reported data contrast with what was observed in Stacy’s classroom observations and accompanying interviews. Stacy frequently gave students opportunities to engage in the intellectual work of the classroom.

To provide an example of what was viewed as instruction that incorporated many opportunities for student epistemic agency, I discuss Stacy’s classroom observations across the three semesters covered in this study: Fall 2018, Spring 2019, and Fall 2019. As presented in Table 13 below, Stacy provided many opportunities for students to do much of the intellectual work in the classroom, with much of the activity centered on students doing this intellectual work while she simultaneously guided them. Additionally, even when Stacy was engaged in directing the intellectual work herself, this often occurred either immediately before or after she guided students in doing the intellectual work. During her third observation in Fall 2019, Stacy discussed in her pre-observation interview that this lesson would be predominantly teacher-led; however, as evident in the visual below, there was still much room for students to do the intellectual work as well. Below, I present examples of what *student doing* looked like in Stacy's observations as well as other instances that were coded as *teacher doing* or *teacher guided* to illustrate the rich epistemic activity occurring in Stacy's instruction and classroom.

Table 13

Epistemic Activity in Stacy's Classroom Observations



Note: Thick vertical line represents the division between days 1 and 2 of the classroom observation. Instances 1-4 noted here are described in detail in text below.

Instance one. In this first example, Stacy asked the class to reflect quietly about the question, "What can looking at rocks tell scientists about the past?" Students were asked to respond to this question in their notebooks. After a few minutes, Stacy asked students to share their answers with the whole class. Below is an excerpt from this whole class discussion in which Stacy guided students through thinking through their own answers:

> Student: It can tell us different things like how dinosaurs looked like...
>
> *Student stumbles and then looks at her notebook again and keeps talking. Stacy is nodding*.
>
> Stacy: So you're saying what they find in the rocks can tell us what used to live back then?
>
> Student: One time my mom found a creature in a rock.
>
> Stacy: Yes, we can know what lives there.

Here, the student was able to share their initial ideas (*student doing*) about rocks and fossils using their prior experience with a rock their mom found (the students' fund of knowledge related to a previous experience with her mother, rocks, and finding a creature). Stacy provided space for the student to think through her answer and re-phrased what she thought the student was saying. Even when the student started to stumble, Stacy did not interrupt to help or finish her answer. Instead, she let the student continue their thought process until they were done speaking. It is also notable that Stacy affirmed the student's response, which was based on a prior experience with her mother; in this way, Stacy also validated the student's experiential knowledge as scientific. The research observer noted that Stacy was generally very encouraging throughout her lesson and noticed that students wanted to speak up even when they were not sure about their answer. This indicates that students sharing their ideas, and thus having space to figure out their ideas about a phenomenon, was a common practice in Stacy's classroom.

Instance two. The above whole class discussion was the context for a demonstration that Stacy eventually provided students when she thought that students were struggling with her explanation of relative dating. She explained in her post-observation interview that students were having trouble conceptualizing how layering worked and how they could see that in rocks. Stacy held up a cup of dirt with a layer of cereal on top to show which layer was newer. This was an example of *teacher doing* to explain a phenomenon that students were having trouble visualizing using materials that they were familiar with from their everyday lives: cereal and dirt. Further, during this demonstration, she leveraged students' prior knowledge to explain relative dating. Stacy explained to students that, "just like we had Newton's laws of physics, we have laws of geology. Superposition says the young rock are the top and old rock is on the bottom" A student in the class responded saying, "We learned about this last year." Stacy affirmed this was true. Finally, another student contributed their interpretation of the rock layers they were observing and said, "So when the rock bends, it is about relative dating." In this exchange, Stacy utilized a *teacher doing* move (a demonstration) to open up a conversation with students wherein they were able to apply what they already knew (laws, superposition) to better understand relative dating.
As is evidenced by the barcode, after Stacy gave this demonstration using the dirt and cereal, she worked with students to guide them through a whole-class discussion. Stacy later explained in her interview that this was a spontaneous demonstration and that she used the

everyday materials she had on hand for this demonstration. This is another example of why teacher directed instruction is not necessarily akin to poor instruction: This demonstration served as an anchor in a whole class discussion in which both students and teacher were doing the intellectual work together, and importantly, Stacy intentionally leveraged students' prior knowledge in this discussion.

Instance three. In her Spring 2019 observation, Stacy began the lesson with the question:

> How do our historical observation of sun, Earth, moon, and stars help us make sense of the universe? It has helped us understand the phases of the moon and seasons. What do we now understand about those and what were the observations?

Students were again given time to quietly reflect and write down their answers. The whole class discussion that ensued was a striking example of students generating their own questions about the universe and Stacy working towards a reflexive teaching practice that made room for student epistemic agency. First, a student generated their own question as part of this larger class discussion.

> Student A: I have a question. You know how the moon is in our solar system. How come we can't see Mars? How come it's not as big as the moon?
>
> Stacy: You can. Oh wait, who wants to answer that?
>
> Student B: The moon is closer.
>
> Stacy: Because the moon is closer. It appears bigger. Our sun doesn't look that big but it's the biggest in our solar system. Mars is really far away. It would take 7 months to get to Mars.

Student B: Knowing how the light works and how the seasons happen, we can predict what will happen.

Here, the student generates his own question about the solar system ("How come we can't see Mars?"). Next, Stacy begins to answer but realizes that this could be an opportunity for a student to show their knowledge instead; in this way, she acknowledges that there are students in her class with prior content knowledge worth sharing. She corrects herself ("Oh wait, who wants to answer that?") and then provides space for a student to offer their own answer. Together, Stacy and these two students work to answer a student generated question. Later in this whole class discussion, a different student generated their own question again.

Student A: What if another planet had a lot of moons? Can we predict those moon phases just like how we predict our moon phases?

Student B: Let's say we did have life in space. What planets do you think it could be coming from?

Stacy: Scientists predict that they could only be coming from habitable planets. Like how we have been talking about.

Student B: I know that there is something that can come crashing to us but it's observable that it is a long time from now.

In this exchange, two students provided questions that arose from careful observation of phenomena in their previous class sessions and generated these questions within a class discussion. This excerpt reveals a pattern in Stacy's classroom of students being encouraged to activate their epistemic agency within whole class dialogues.

Overall, this format was a typical representation of the lessons observed in Stacy's classes and seemed to be a discursive practice that was familiar to students as well. Stacy discussed several times in her interviews the idea of shifting the teacher student relationship towards one of mutual dialogue. She discussed students as being "curious" about content (rather than simply not knowing); that is, she positioned students not as empty vessels who did not know anything, but rather as curious about what they do not know.

Instance four. In this instance, Stacy said to students, "Today's lesson is a lot more teacher directed instruction than normal." This was the only observed instance of any teacher explaining to students when *teacher doing* instruction would occur (versus *student doing* or *teacher guided* instruction). In this case, Stacy explained that she would be doing a lot of the work (which Stacy explained in her interviews was atypical). This was also an interesting proclamation to make in hindsight given the number of instances of students doing the intellectual work in this Fall 2019 observation.

Specifically, she also mentioned and was observed explaining to students why sometimes she did direct instruction in her Spring 2019 observation. This type of explicitness involved students in the process of the class and treated them like partners in the learning process. It is also telling that she expressed a reason for teacher directed instruction – instead of trying to argue for why direct instruction is still exploratory in small ways (e.g., students get to choose the color of the gummy bears in an investigation). She acknowledged that the instruction was direct and explained why it was necessary (to researchers in interviews and students in class alike). However, when we examined her observation in the Spring of 2019 more closely, we noticed that although there was more activity coded as *teacher doing* than her previously observed lessons, there were still several instances of the *student doing* code present. This is interesting to note because even when Stacy thought that she was doing direct instruction in which there was a lot of *teacher doing* instruction, she was still providing students opportunities for agency; students were still generating their own questions, constructing their own explanations, and otherwise engaged in their own process of learning science. It is also important to note that her class was more than two-thirds female.

However, despite her apparent success at enabling student agency, in her interviews, Stacy expressed that she also struggled with giving students agency. She described a tension she sometimes felt saying,

> Students are supposed to explore to come up with their understanding and when they're really off, at what point do you step in? Or do you just keep doing investigations and what if half of them still don't understand what the hell you're talking about?

In this sense, Stacy acknowledged that she thought students *should* be coming up with their own understanding of material but struggled with knowing exactly how to guide students in doing so. While Stacy expressed uncertainty about knowing exactly how to guide students to construct their own knowledge, she also presented a strong example of teachers as critical guides and expert professionals in the classroom.

2. Case Study #2: Katie from La Paloma

Next, I present findings from the analysis of Katie's observations across the three semesters. In her survey responses, she had the highest overall self-reported frequency of engaging students in the SEPs as a whole across the study. For planning and carrying out investigations, she rated her frequency of enactment highest of all six case study teachers, saying students conducted investigations weekly or more in all three semesters. Her observed instruction provided many opportunities for small group work for students to work together. Like Stacy, she also had many examples of using *teacher doing* instruction to leverage *guided* or *student doing* activity. It is important to note that, overall, Stacy had more activity units throughout her observations; Katie had less so there are less instances highlighted below the table. Table 14 below gives the barcode visual for her observations across the three semesters.

Table 14

Epistemic Activity in Katie's Classroom Observations

Fall 2018 Classroom Observation – MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.					
Time	7:33am	7:42am	8:00am	8:15am	8:29am
Teacher Doing					
Teacher Guiding				1	
Student Doing					

Spring 2019 Classroom Observation – MS-LS1-2: Within cells, special structures are responsible for particular functions, and the cell membrane forms the boundary that controls what enters and leaves the cell.				
Time	8:35am	8:50am	9:00am	9:13am
Teacher Doing				
Teacher Guiding				
Student Doing			2	

Fall 2019 Classroom Observation – MS-ESS2-4: Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity				
Time	10:15am	10:35am	10:47am	10:53am
Teacher Doing		3		
Teacher Guiding				
Student Doing				

Note: Thick vertical line represents the division between days 1 and 2 of the classroom observation. Instances 1-3 noted here are described in detail in text below.

Instance one. In this first example, Katie led students through a discussion about defining the word "brainstorm" to begin the engineering design task to design a solution to conserve water. She asked, “Have you ever heard the term brainstorm?” One student, connecting this question to their prior knowledge, stated, “I heard it the other day…. It’s when you work collaboratively.” Another student then contributed, saying, “I think it’s when you’re thinking of ideas together.” At this moment, Katie gave instructions on how to structure their discussion, saying, “Guys, remember to feed off the person before you. Agree and disagree.” A third student took this direction and said, “It’s what Sarah and Hailey are saying. Where you think about stuff and bounce ideas off of each other.” Katie acknowledged this student saying, “I like that you gave the other students credit.” In this exchange, Katie explicitly called out how students should engage in a discussion (“feed off the person before you”) and encouraged students to share their initial ideas about what it means to brainstorm based off their prior experience with the word.

Instance two. In this second example, Katie was gearing up for a lesson on how kelp is a system. To familiarize students with the different pieces of a system (e.g., components, flow, boundaries), she had them discuss systems that they might already be familiar with. She asked students, “Think about something in your life that is important to you. Volleyball, baseball, soccer, Fortnite, a bicycle maybe. When you think about that, what are the components needed to use it or do it?” Students were encouraged to think about their personal interests as the basis for their discussions with their peers. Students worked in small groups to talk about what important thing in their life they had chosen and identify the components. One small group of students was overheard by the observer having the following discussion:

Student A: Fishing

Student B: I chose fishing too.

Student C: What does she mean about component?

Student A: Something that's a part of something.

Student B: So like my fishing pole.

Student A: And your line.

In this discussion, students supported their peer who was unsure what Katie meant by "component" and used their experiential knowledge related to fishing to define what components or parts make up a fishing rod. This is an example of where the discussion was coded as *student doing* in the context of a lesson that had been decided by the teacher. In other words, the task itself might not have been student generated, but discussion included students' ideas.

Instance three. In this last example, Katie led a discussion that was coded as *teacher doing* but drew on students' prior knowledge from a lesson earlier in the year. Katie asked students to remember when they were learning about the water cycle and pretended to be a water droplet going through the water cycle. Katie asked a volunteer to "tell me some places you went" when they were a water droplet. One student raised their hand and said, "Glacier, ocean, cloud." Several other students shouted out and supplied other answers from what they remembered from the activity. Katie followed up with a question, "How many of you spent time in the ocean?" Many students raised their hands and she asked, "Right, why was that?" One student explained that "there was only one way out of the ocean. Evaporation." This pattern of questions and answers continued for many minutes. Although students were prompted to access their prior knowledge to engage in the discussion, these questions were closed-ended and thus this activity unit was coded as *teacher doing*.

Not necessarily related to epistemic agency specifically, in her interview associated with this observation, Katie also discussed how she sent out a survey to students to ask them what specifically they liked and disliked about the lessons in class and tailored her lessons to better address what the students were looking for. In this way, Katie pulled on students' own ideas about how they preferred to learn science. While this is interesting to note, this is an example of increased general student agency rather than epistemic agency specifically.

Summary

As was described earlier, the *teacher doing* code was not seen in the data as frequently as *teacher guiding* instruction, but it was seen more frequently than *student doing* activity. There were only 12 instances of *anti-guiding instruction*, but these served as important reminders. There were several important challenges that teachers discussed in their interviews related to implementing *student doing*: embracing chaos, feeling constrained by the standards and reform-oriented science education (e.g., teachers stated they did not feel they could do the NGSS 'the right way' if they did direct instruction), and lack of available curriculum. When teachers drew on students' funds of knowledge in the context of doing the SEPs, they were most frequently drawing on students' knowledge about socioscientific issues, prior content knowledge, and community or local geography.

Lastly, going beyond the numbers and coding counts, the cases of Stacy and Katie showed that students were engaged in collectively learning from each other. In summary, Stacy put her approach succinctly saying she intentionally created opportunities for students to engage in argument with each other because,

> They're learning to really listen to their peers and learn from each other because we talk so much about you're building knowledge as a class. And so it's not about what

> one person knows or doesn't know, but it's like collectively, how can we kind of build that knowledge.

These two teachers were observed adopting pedagogical approaches that were based on the premise that students and teachers can learn from each other. In the following chapter, I discuss findings from the student surveys to better understand whether students thought that they were the ones doing the SEPs and that their lived experiences mattered in their classes.

VII. Teacher and Student Survey Findings

The final research question asked about comparisons between teacher survey and student survey results as well as student impact of NGSS instruction. In this chapter, I first discuss findings related to student impact and whether students reported seeing science as interesting and relevant to their lives outside of school. Next, I compare student survey findings to teacher survey findings from the first findings chapter. As part of this comparison, I conducted one ANOVA comparing the student responses from focal teachers for epistemic agency and one t-test for funds of knowledge. The groupings for each of these statistical tests were based on whether teachers were high, medium, or low for each construct, which can be found in the first findings chapter in Table 11.

A. Whole Sample Student Survey Findings

First, I examined student responses from all 19 study teachers. To analyze the survey responses, the responses were assigned a corresponding value that aligned with the ordinal nature of the survey items. As such, a value of zero corresponded to survey responses that indicated an action or behavior was never performed. Increasing values of one, two, three, four, and five, if necessary, indicated increasing endorsements of the action or behavior. For Question 1 and Question 2 in Table 15 below the response option scale was as follows: 0 (never), 1 (less than monthly), 2 (monthly), 3 (every two weeks), 4 (weekly), or 5 (almost daily). For Question 3 and Question 4 in Table 15 the response option scale was: 1 (strongly disagree), 2 (somewhat disagree), 3 (neither agree nor disagree), 4 (somewhat agree), or 5 (strongly agree). The surveys were then examined using descriptive statistics. This allowed me to begin to understand how often and to what extent certain practices were being reported by both teachers and their students.

The student surveys from all 19 study teachers (n=901) reveal that the content of scientific questions and investigations as perceived by the students was often about sources external to the student (see Table 15). Responses to Questions 2a and 2b show that students reported they were investigating questions or problems posed by either something happening somewhere else in the world or something from a textbook, worksheet, or other material that the teacher gave them slightly more than monthly (*M*=2.26). Comparatively, responses to Questions 2e, 2g, and 2h show that students reported the investigations were derived less often from their community (*M*=1.80), something that had happened to themselves or their peers outside of class (*M*=1.48), or something going on at home (*M*=0.95). In other words, students felt that the source of the questions and investigations in their class was more often about a source external to them (textbook, worksheet, etc.), rather than being derived from the students themselves or their community outside of school. These findings indicate that as the sources of questions and investigations move towards being more student-generated rather than teacher-generated, the instances of these sources decreased. For example, as shown in Table 15, as the source of investigations in the classroom moves towards the individual student, the average reported frequency of implementation decreases.

Table 15

Student Survey Item Analysis

Student Survey Question	Response Options	Mean	Mode	Standard Deviation
1. How often has your science class investigated questions or problems posed by the following?	a. The teacher	2.39	3	0.90
	b. The class	2.23	3	0.84
	c. The book or worksheet	2.10	3	0.92

	d. Your small group	1.96	2	0.87
	e. Your community	1.61	2	1.01
2. How often has your science class investigated questions or problems about the following?	a. Something going on somewhere else in the world	2.26	3	0.79
	b. Something from a textbook, worksheet, or other material the teacher gave me	2.26	3	0.83
	c. Something that my class and/or I saw (either in person or in a video)	2.16	2	0.85
	d. Something that is interesting to me	2.05	2	0.87
	e. Something in my community	1.80	2	0.86
	f. Something that didn't make sense to me, and I couldn't figure it out	1.72	2	0.91
	g. Something that has happened to me or others in my class	1.48	2	0.96
	h. Something going on at home	0.95	0	0.99
3. What we do and learn about in science class:	a. Matters to my teacher	4.29	5	0.97
	b. Matters to me	3.86	4	1.06
	c. Matters to the class	3.84	4	0.97
	d. Matters to the community	3.83	4	1.04
	e. Doesn't matter to anyone	2.11	1	1.22
4. Select how much you agree or disagree with the following statements:	a. Science can help to solve problems in the world	4.17	5	1.00
	b. Science can help me understand the world	4.04	5	1.04
	c. Learning science can help me in my life outside of school	3.77	4	1.05
	d. Listening to other students in class usually	3.68	4	1.09

helps me improve my thinking			
e. I am usually comfortable sharing my ideas with my science class	3.29	3	1.21

Note: For Question 1 and Question 2 the response option scale was: 0 (never), 1 (less than monthly), 2 (monthly), 3 (every 2 weeks), 4 (weekly), or 5 (almost daily). For Question 3 and Question 4, the response option scale was: 1 (strongly disagree), 2 (somewhat disagree), 3 (neither agree nor disagree), 4 (somewhat agree), or 5 (strongly agree).

However, as evidenced by responses to Questions 3a-e, students still agreed that science mattered to themselves (*M*=3.86), their class (*M*=3.84), and their community (*M*=3.83). However, the reported average frequencies for these three items (Questions 3b-d) were slightly less than science mattering to their teachers (Question 3a, *M*=4.29). Students reported science as mattering to them personally as well as their communities, despite the content of their classes not necessarily being generated by them or their communities (as evidenced by responses to Questions 1a-e). In summary, student surveys indicate that students saw science as relevant to the world, whether through teacher videos, textbooks, or field trips, but they saw the content as mattering more to their teachers than themselves, their class, or their communities.

According to student responses to Questions 4a-c, they generally agreed that science was interesting and that they saw applications for science outside the classroom, but as mentioned above, they saw it as mattering more to their teacher than to them as individual students, their community, or their own peers. This follows given responses to Questions 1a-e that investigations were primarily driven by the teacher and textbooks rather than individual students, classes, or home life. Students reported that they found science content to be generally interesting and relevant to problem solving and understanding the world, though not necessarily mattering to themselves or their communities.

B. Focal Teacher Survey and Student Survey Findings

In this section, I describe the student survey findings for the six focal teachers and how their student survey findings compare with the teacher survey findings. Table 16 below reports the average epistemic agency score across both study years from the student survey and teacher survey, respectively. Review the Appendix for the items that were included to calculate the epistemic agency composite score for teachers and students as well as the items for funds of knowledge for teachers and students. It is important to note that the items that comprise the epistemic agency score for students derived from items that were, at times, slightly different than the items for teachers. The response option scale from the teacher survey items were as follows: 1 (never), 2 (sometimes), 3 (often), and 4 (all or almost all the time). The response option scale for students was as follows: 0 (never), 1 (less than monthly), 2 (monthly), 3 (every two weeks), 4 (weekly), or 5 (almost daily). In other words, teachers and students were asked different questions but the sets of items for both groups were intended to measure frequency of epistemic agency and funds of knowledge implementation. Given this limitation, there were differences in average scores between teachers and students for how frequently teachers reported engaging students in the SEPs (a proxy used to understand how often *students* were doing the activity in the classroom). There were also differences in frequency of implementation for funds of knowledge between teachers and students. Table 16 below shows these data.

Table 16

Average Scores for Focal Teacher Surveys and From Their Student Survey for Both Study Years

Focal teacher	Number of students across both years*	Average epistemic agency score across both years as reported by students	Average epistemic agency score across both years as reported by teachers	Average funds of knowledge score across both years as reported by students	Average funds of knowledge score across both years as reported by teachers
Stacy	120	3.53	1.81	3.87	3.00
Louis	66	3.02	1.80	2.42	2.53
Kiley	184	2.94	2.90	2.40	2.99
Andrea	66	3.32	2.29	2.26	3.23
Katie	68	3.26	2.44	2.25	3.41
Lydia	42	1.96	2.95	1.91	3.17

Note. *This number varies between teachers depending on how many science classes they taught in a year and how many students both consented to participate and responded to survey items.

First, I compared student and teacher scores for epistemic agency. All six sets of classes, except for Lydia's classes, had students report that they engaged in the SEPs more frequently than teachers did. In other words, Stacy, Louis, Kiley, Andrea, and Katie reported that they engaged students in the SEPs less frequently than their students reported doing so. Stacy had a 1.72 difference between the score she reported in her survey (M=1.81) and what students reported (M=3.53). Given that a score of three meant "often" and four meant "all lessons," Stacy's students reported that they were engaging in the SEPs more frequently than "often." Stacy herself reported that she did this more than "never" but less than "sometimes." The student score resonates with her observations because she was seen frequently guiding and engaging students in the SEPs. Student survey scores and observations suggest that she may have underrated herself in her own survey responses. Louis is also one focal teacher whose students reported more frequent engagement in the SEPs than he did in his survey. His students reported an average score of 3.02 while he reported 1.80 for a difference of 1.22. Kiley and her students were more aligned: Her students reported a frequency of 2.94 and she reported a score of 2.90 (both equating to engaging in the SEPs more than sometimes). Andrea and Katie each had approximately a one-point difference between their student and teacher average scores, respectively. As stated above, Lydia was the only teacher who reported more frequently engaging students in the SEPs than her students did. It is also important to note, however, that she had the smallest student sample with 42 students.

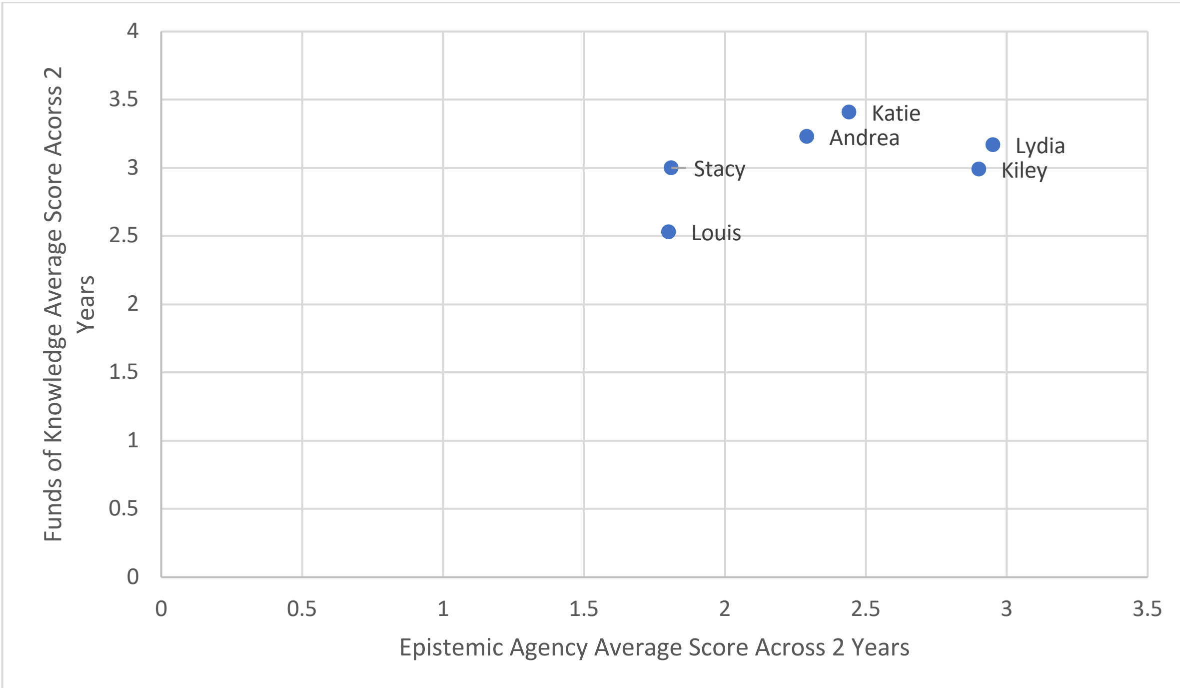
In terms of funds of knowledge scores, Stacy was the only teacher whose students reported that they participated in lessons that drew on their funds more frequently than their teacher reported doing so. Stacy reported a frequency of 3.00 but her students reported a score of 3.87, meaning they reported that they were participating in lessons they saw as relevant to them more than often than Stacy. The other five focal teachers reported that they engaged students in lessons that drew on their funds of knowledge more frequently than their students reported doing so. However, it is important to note that as a whole, teachers reported very high funds of knowledge implementation scores compared to epistemic agency scores. Teachers reported scores higher than 3 (meaning more than "often") whereas students in everyone's classes (except Lydia) reported scores below 3 but above 2 (meaning more than "sometimes"). Lydia had a score below two, corresponding to an average response of less than "sometimes." This is to say that although students reported a smaller average than teachers did, the averages were still above 2, meaning they felt they were engaging in meaningful lessons more than sometimes.

C. Between-Group Comparisons: Differences in Student Survey Responses Between Teacher Groups

I conducted an ANOVAs to see if there were any meaningful differences between the student responses for teachers who scored themselves high, medium, or low on epistemic agency and a t-test for whether they scored high, medium, or low on funds of knowledge. See Figure 5 below for a graph that shows teachers' scores as a function of their average for epistemic agency and funds of knowledge. This graph was the basis for the groupings for the ANOVA and the t-test. The ANOVA examined differences in student responses between groups based on whether teachers reported a high, medium, or low average on epistemic agency; based on the findings in Table 11 in the first findings chapter, Louis and Stacy were grouped together as 'low', Andrea was 'medium,' and Kiley, Katie, and Lydia were 'high'. A t-test was used for whether teachers scored themselves high or medium on funds of knowledge; there were no focal teachers that rated themselves 'low' for funds of knowledge. For this test, Louis was grouped as a 'medium' funds of knowledge teacher and Kiley, Katie, Stacy, Andrea, and Lydia were grouped as 'high' funds of knowledge teachers. An unpaired t-test was chosen because the data were collected from different individuals over different days. The analysis was done in R (R Core Team, 2022).

Figure 5

Teacher Epistemic Agency and Funds of Knowledge Average Score Comparison



The purpose of the ANOVA and the t-test was to see if there were any meaningful differences between student responses based on whether their teacher was high, medium, or low on each construct. In other words, I was interested in finding out whether there were significant differences in student responses between teachers who rated themselves high, medium, or low on either construct.

From the ANOVA, there was a significant difference between the student report scores at the $p<.05$ level for the three categories of low, medium, and high [$F(176, 2) = 3.74$, $p=0.02$)]. This indicates that there was an impact on how the students reported their own epistemic agency depending on how their teacher self-reported. In other words, there was a difference in how students reported whether they were the ones doing the SEPs compared to the reports in teacher surveys.

To investigate this difference further, a Tukey's post-hoc test was conducted. This analysis revealed that the mean difference between the high and medium groups ($\Delta\mu = 0.37$, $p=0.04$) was significant at the $p<.05$ level (but there was no difference between low and medium or low and high). This indicates that there was a difference in how the students in the medium teacher group reported engaging in the SEPs compared to the students in the high teacher category. In other words, the students in the medium teacher group (*M*=3.34, *se*=0.14) more closely reflected their teachers scores compared to the students in the high teacher group (*M*=2.97, *se*=0.09).

While there were not significant differences between student responses in the low teacher group and the medium or high teacher groups, there were still differences in the means for reported engagement in the SEPs. The mean student response for low teachers was 3.31, the mean for the medium teachers was 3.35, and the mean for high teachers was 2.98. This means that the students in the high teacher group did not rate their teachers as highly as their teachers did and in fact, rated their teachers lower than the students in the low and medium groups. This was an unexpected finding as I thought that there would be more agreement between teachers and students, so I also examined the medians for each group. The median for the low teachers was 3.33, the median for the medium teachers was 3.45, and the median for the high teachers was 2.94. Since these medians are close to the mean, the means are accurate reflections of the average student response. The students rating the low teachers as having higher frequency of implementation of epistemic agency might be due to Stacy. As we have seen in interviews, observations, and descriptive statistics of student survey responses, Stacy's teacher survey responses did not accurately capture how frequently she was indeed enacting student epistemic agency. In other words, because she rated herself lower than what she was doing in the classroom, her student responses might have raised the mean for the low epistemic agency teacher's group.

Next, I grouped teachers by the second construct, funds of knowledge. The medium funds group was Louis, and the high funds group was Kiley, Stacy, Katie, Andrea, and Lydia. The findings were not statistically significant, but the means were slightly different. Those teachers who rated themselves lower for funds of knowledge had students who also rated their implementation of funds low (M=2.31) and those teachers who rated themselves higher had students who also rated their implementation of funds higher (M=2.30). Like the findings for epistemic agency, students in the lower group (in this case the medium group) reported a higher frequency of implementation on average than teachers in the higher group, although the differences were small and not statistically significant. This finding makes sense given that there was not much variation amongst teachers for funds of knowledge (all teachers except for Louis were rated as ‘high’).

In summary, there were statistically significant differences between groups for epistemic agency, but the direction of this difference was surprising. Students whose teachers rated themselves low or medium for epistemic agency reported a higher frequency of implementation when compared to student responses from teachers who rated themselves high for epistemic agency. This finding was also true for funds of knowledge (medium teachers had students report higher funds of knowledge implementation than high teachers) but these differences were small and not statistically significant.

D. Summary

Descriptive analysis of student responses for the epistemic agency questions revealed that, overall, students reported the content of the investigations and questions asked in class was more often generated from the teacher than themselves, their peers, or their communities. However, despite not being the ones deriving the questions used for investigations in class, students still reported that they saw science as mattering to themselves and their peers and agreed that science could help them understand the outside world and their lives outside of school. Student reports disagreed somewhat with teacher reports about how frequently they were engaging in the SEPs and engaging in lessons that drew on their funds of knowledge; students whose teachers rated themselves high reported less frequency of implementation for both constructs than students whose teachers rated themselves low or medium. Further, these differences for the epistemic agency items were significant.

VIII. Discussion

In this study, I examined whether or how often middle school science teachers enacted student epistemic agency by drawing on their funds of knowledge in the context of a widespread standards implementation effort. This dissertation expands on previous work by including a larger sample of 19 middle school teachers, with varying teaching experience and curriculum available to them, and by examining several different data sources from both students and teachers to try to capture their rich experiences in the classroom (González-Howard & McNeill, 2020; Ko & Krist, 2019; Penuel et al., 2022; Stroupe et al., 2018). Additionally, within epistemic agency literature on secondary science classrooms, little research has been done relative to funds of knowledge (Penuel et al., 2022; Sezen-Barrie et al., 2020). This study expands on previous research regarding epistemic agency in secondary classrooms by including funds of knowledge as a construct for analysis (Miller et al., 2018). My research questions were: 1) How often did middle school science teachers across California create opportunities for students to activate epistemic agency in engaging with the science and engineering practices and draw on students' funds of knowledge? 2) What opportunities for epistemic agency did middle school science teachers discuss and ultimately enact in their classroom by drawing on students' funds of knowledge? And 3) When teachers enacted epistemic agency by drawing on students' funds of knowledge, what was the student impact on how they saw science as relevant to them? In this chapter, I discuss the qualitative and quantitative findings taken together organized by research question and how these findings connect with and advance prior research in the literature.

A. Frequency of Opportunities for Epistemic Agency Tied to Funds of Knowledge

There were no consistent patterns between which teachers reported high or low frequency of implementation of epistemic agency and funds of knowledge in either study year related to the teachers' district and level of NGSS support. This contradicts prior research that has shown that professional learning is an important support for teachers' NGSS implementation (Tyler et al., 2020). This finding could be due to the varied levels of professional learning that teachers individually participated in. As a reminder, 13 of the study teachers in the Valley Creek, Kenmore, Glacier, and La Paloma districts received professional learning as part of the Early Implementer's Initiative (Tyler et al., 2020). This particular professional learning was extensive in that it was offered over a prolonged period of time (several years). The five teachers in the Tidewater district received comparatively less NGSS professional learning. Teachers in the Tidewater district did receive some professional learning from their district, but it was not sustained over several years. The final two teachers in the Ravenview district did not receive any professional learning from their district regarding NGSS and any professional learning that teachers did report engaging in was voluntary and at their own discretion. It is also important to note that although the professional learning was offered, it was not mandatory in any district, and as such, the reported hours of professional learning that various teachers engaged in did not necessarily align with whether the district was labeled as "extensive", "moderate", or "no" support.

The fact that any professional learning offered was not mandatory meant that teachers in each individual district might have participated in more or less professional learning than teachers in the same district. For example, Table 1 in the methods chapter shows that Megan reported participating in 6-15 hours of professional learning while other teachers in her district reported 80 hours or more. In this way, a teacher in a high support district could have participated in less professional learning than those in a no support district. Perhaps a more longitudinal study would find differences between teachers who received extensive professional learning and those that did not and in future work I could group teachers by the number of hours of professional learning they participated in rather than their district.

Overall, there were increases in teachers' reported average implementation for epistemic agency and funds of knowledge across study years. This increase in implementation is perhaps due to teachers and students becoming more comfortable with the standards and thus feeling more comfortable engaging students in the SEPs by implementing lessons that leveraged students' funds of knowledge. This comfortability factor might also explain why funds of knowledge averages were higher across all 19 teachers when compared to the epistemic agency averages; funds of knowledge was likely to be a more familiar construct to teachers than was epistemic agency, since funds of knowledge has a longer history in the literature (Moll et al., 1992). Furthermore, when looking at the high, medium, and low categorizations for each construct, importantly, all teachers who scored high for epistemic agency also scored high for funds of knowledge (except for Jasmine who was in the medium group for funds of knowledge). The reverse was not necessarily true for the low epistemic agency scores; in other words, if a teacher scored low on epistemic agency, they could be considered high, medium, or low for funds of knowledge. However, epistemic agency averages also might be lower when compared to funds of knowledge because teachers might have been doing more of the cognitive work to support students new to the SEPs. For example, while students might have been doing the investigations, teachers supported students to do this by planning the investigation as evidenced by a higher average frequency of “students doing investigations” than “students planning investigations” in the teacher surveys. Just as teachers were new to the standards, so were students and teachers might have needed to do much more scaffolding in the first year than in the second.

While teachers reported that students were the ones doing investigations and other SEPs, students reported that the source of the questions and investigations in their class was more often derived from a source external to them (like a textbook, worksheet, or other material that was given by the teacher) rather than being derived from the students themselves or from their communities. This may be due to teachers’ perceived role in the classroom as classroom manager and leader, their students’ roles as learners, or other factors such as lack of curriculum or administrator expectations. This aligns with prior literature that has found that teachers often underestimate the extent of pedagogical shifts required to enact student epistemic agency, even despite their expressed goals to do so (Kawasaki & Sandoval, 2020). The challenges that teachers encountered when implementing epistemic agency and funds of knowledge was further discussed in interviews and was observed in classroom observations. These challenges will be discussed in the section below pertaining to my second research question.

B. Discussion of Opportunities for Epistemic Agency Tied to Funds of Knowledge

In their interviews, all teachers expressed a desire for students to engage in activities agentively. However, as seen in teacher surveys, teachers implemented epistemic agency less often than they did funds of knowledge. As mentioned earlier, having students participate in knowledge generation is not as simple as one might think (Suh et al., 2022). Some teachers discussed how they struggled with enacting epistemic agency because this meant that students were doing the cognitive work. Teachers were thus tasked with guiding students through the epistemologies of science, helping them to figure out the how and why of science. Kiley explained that "when students get to make their own decisions, dealing with the chaos… it can be a lot." When many students become involved in the activity of figuring out a phenomenon, the classroom may feel chaotic. Teachers expressed concern and confusion about what their role was amidst calls for student-centered instruction. Some teachers expressed that they still needed to be facilitators of students' learning and expressed concern for what they perceived to be a call for little teacher guidance in science education. This would naturally be concerning for teachers who play an important and valuable role in teaching and learning. As we saw in Stacy's instances, having a teacher closely attuned to how they were supporting student agency led to deep and powerful learning experiences for students. Teachers in the study like Stacy understood that there was a necessary balance between direct teacher instruction and student-centered inquiry.

In general, the teachers included in this analysis demonstrated an understanding of and desire to enact activity that encouraged students' epistemic agency and drew on students' funds of knowledge. This was evidenced by 95 instances of teachers drawing on students' funds of knowledge when guiding intellectual work and 59 instances of funds of knowledge when students were doing the intellectual work. There were also certain teacher moves that were observed in classroom observations that allowed for student participation in the process of learning as well as dialogic inquiry between teachers and students (questioning strategies, engaging students in a process of learning, etc.) that extended from students' prior content knowledge and familiarity with practices like claim, evidence, reasoning.

However, in their interviews, teachers discussed the challenges with engaging student epistemic agency by drawing on student funds and attributed this to several different reasons. First, teachers cited lack of curriculum as a barrier to engaging students in the cognitive work of the class activity or giving them material to work off to tap into students' funds of knowledge. At the time of the study, teachers needed curriculum to support them in implementing the standards in such a way that allowed them to enact epistemic agency by drawing on students' funds of knowledge. Furtak and Penuel (2018) argued similarly, stating that there is a need for curriculum that is developed in-line with students' own questions and allows them to iterate through the scientific practices. Teachers were lacking a curriculum that supported them in drawing on the specific interests and knowledges of the unique students in their individual classrooms, which assisted the iterative process of science to proceed. Engaging students in the cognitive work of science is time-consuming, and without curriculum, teachers' time was constrained because they needed to be both teacher *and* curriculum developer. The data for this study were collected just 5-7 years after the NGSS were adopted in California, so curriculum was not widely available to teachers at the time. As NGSS-aligned curriculum becomes available to teachers, research should be done as to whether or how newly developed curriculum supports teachers to engage students' epistemic agency by drawing on their funds of knowledge.

Teachers also expressed struggling with guiding students to construct their own understanding of material in a way that aligned with their out of class knowledge but also aligned with scientific consensus without providing direct instruction. For example, Stacy said, "Students are supposed to explore to come up with their understanding and when they're really off, at what point do you step in? Or do you just keep doing investigations and what if half of them still don't understand what the hell you're talking about?" Even an exemplary teacher like Stacy commented in her interviews that she had questions still about how to get students to know the content they needed to know while still making space for students to raise their own questions and define their own problems, for example. This aligns with prior literature that has discussed the persistence of the 'classroom game' (Hutchison & Hammer, 2010) which is heavily influenced by state testing demands put on teachers and schools. When students and teachers alike work within a larger educational system that rewards certain kinds of knowledge, it is unproductive to move away from traditional rules or norms. Teachers in this study said in interviews that they wanted to make room for student agency and understood the importance of drawing on students' funds of knowledge to do so, but were less certain about pedagogical practices that they could use to expand the discipline of science beyond how it had been traditionally taught. As such, teachers like Lydia creatively looked for other ways to give students a sense of agency in the classroom. For example, Lydia looked to give student agency through providing them choice or opening up the door for feedback about lessons she taught. In this way, she tapped into students' preferences about how they learn. While it is certainly important to engage students in the classroom community in this way, this was not offering students specifically epistemic agency in science. That is, these kinds of choices offer a superficial level of general agency but not epistemic agency in engaging in the SEPs. As stated previously, epistemic agency in the SEPs is important for students to avoid running the risk of epistemic injustice (Stroupe et al., 2018). We saw an example from our own study that bordered on epistemic injustice: Andrea called into question the value of a student's genuine question about atomic size ("Aaron, who cares?"). While our observations account for only a snapshot of a teacher's classroom in the context of a whole year, these kinds of instances when compounded over a student's academic career can have meaningful and long-lasting impacts on their ability to see themselves as capable scientists.

Teachers' concerns that they needed students to learn certain content is understandable given the context of this study was a large-scale standards roll-out endeavor where standards implementation was the focus of the larger study. The lessons observed were intended to be NGSS-aligned and as such it is hard to say that students were going to be given opportunities for anything other than standards-sanctioned science. Prior research has problematized the NGSS as simply another set of standards that suggest students be "doers" of science, so long as they are doing the science that is outlined in the standards (Miller et al., 2018). That is, standards-sanctioned science is the science that students should be doing. In this study, teachers certainly struggled with wanting to take up students' genuine questions and spend time engaging them in the epistemological practices of science but were constrained by requirements for students to learn certain content and meet state standards that did not necessarily align with students' home or community knowledges. The findings align with prior findings from Miller et al. (2018) in that teachers were only able to go so far as eliciting student ideas that were recognizably aligned to the standards. More research needs to be done on whether or how opportunities are provided for students' home and community-based intellectual resources to be seen as valuable science work in the constraining context of standards-based education.

C. Student Survey Themes

In general, there was some agreement between what teachers reported and what students reported for funds of knowledge. Teachers reported frequently drawing on students' funds of knowledge with about one third of teachers reporting a frequency of implementation more than “often.” Students reported that they investigated questions or problems about something going on in the world, something that was interesting to them, or something that they as individual students or that the whole class had seen before either in person or in a video more than “sometimes.” Further, students reported seeing science as relevant to their lives outside of school. This is an important success to highlight. Rodriguez (2013) argued that there has been less emphasis on the ‘why’ of funds of knowledge, which is to engage and empower students and their communities. In this study, students overwhelmingly reported that they saw science as relevant to their lives outside of school, saying that they strongly agreed that science can help to solve problems in the world, can help them to understand the world, and can help them in life outside of school. All three of these items (that science can help solve problems in the world, can help them understand the world, and help with life outside of school) had a student reported average at 3.77 or above, meaning students agreed more than “somewhat.” This finding makes sense given discussion in teacher interviews that teachers were attuned to guiding students to see the application of science outside of the classroom.

In their interviews, all teachers expressed a desire for students to engage in activities that were relevant to their lives outside the classroom. Stacy explained her reasoning as to why she thought it was important for students to believe that science is a way of knowing that they can successfully leverage outside of the classroom, saying,

> They don't think they can be scientists at this point, not most of them anyways. And so, if we can show them, like you can do what scientists do, then it can push them to that as well. Their eyes will be open to all the different fields of science and things they could do with it.

In general, the six teachers included in the interview analysis demonstrated an understanding of and desire to enact student epistemic agency in a way that empowered students to both see and use science in their daily lives. While students seem to have left the classroom understanding the applicability and utility of science outside of class, they reported that the content covered in class was not frequently something that was going on outside of class, in their home or community. According to student reports, the content of teachers' lessons were more frequently generated by the teacher or textbook rather than something going on at home or something by the student or small group. This finding makes sense given the struggles that teachers discussed in their interviews mentioned above; teachers understood why it is important to allow students room to generate their own scientific questions but were less certain about how to do so, especially given constraints for students to know particular content. This might explain why students reported that the investigations and questions posed in class were often generated by the class as a whole. Students did report an average of 2.23 (meaning more than "sometimes") for questions and problems being posed by the class which includes students. According to student report, teachers were engaging students as a whole to generate questions and investigations that they did in class. This follows given the large number of "guiding" codes observed in classroom observations. As evidenced by classroom observations, there was a lot of teacher guiding students to decide on questions and investigations as a whole class group which is the kind of group-based dialogic learning discussed in prior literature (Ko & Krist, 2019; Miller et al., 2018). The large number of guiding codes and the average frequency of the whole class generating questions and investigations reported in student surveys suggests that students and teachers were working together to identify and figure out phenomena.

However, there were some differences between teacher and student reports for epistemic agency. The results of the ANOVA in which the comparison groups were students of teachers who rated themselves high, medium, or low for epistemic agency were statistically significant. In other words, students who had teachers who rated themselves low for epistemic agency (Stacy and Louis) as well as students whose teachers rated themselves medium (Andrea) reported significantly more epistemic agency implementation than students whose teachers rated themselves high for epistemic agency (Katie, Lydia, and Kiley). If teachers and students had agreed, the outcome would have been that the highly rated teachers would have had a higher average than the lower rated teachers. The outcome was the opposite of what was expected; I would expect that if students agreed with their teachers, that those students who had teachers that rated themselves high for epistemic agency would have a higher average than the students whose teachers rated themselves low or medium for epistemic agency. Rather, the average between groups were statistically significant in the opposite direction than what was expected.

Taken together, these findings align with prior research in that students were learning content that they thought was relevant to their lives outside of school but that students were not the ones doing the cognitive work to answer their own questions, plan their own investigations, etc. In this study, students reported covering content that mattered to them (with an average score of 3.86, meaning they more than "somewhat" agreed) but teachers and textbooks decided what was investigated and how. Students reported that teachers decided what was investigated more than "sometimes" and that students got to decide what was investigated slightly more than "not much." This aligns with prior research that critiques funds of knowledge approaches for not going far enough in disrupting traditional classroom power dynamics such that teachers and students learn from each other (Rodriguez, 2013). This study lends some evidence that drawing on students' funds of knowledge and including content that students find matters to them does not necessarily mean that students are given agency in the classroom. Further work should be done to understand how to better support student epistemic agency when teachers tap into their funds of knowledge.

D. Implications

There are three major implications of the findings of the study. The first is for research: This dissertation contributes to previous literature on epistemic agency as well as funds of knowledge approaches in science education by investigating how middle school science teachers capitalize on students' funds of knowledge in such a way that empowers them to enact their own epistemic agency. These findings extend the literature on funds of knowledge. Prior research has called for funds of knowledge approaches to incorporate student agency as a construct for research (Rodriguez, 2013). This dissertation considers not only funds of knowledge as a singular approach but also epistemic agency. Additionally, within epistemic agency literature on secondary science classrooms, little research has been done relative to funds of knowledge (González-Howard & McNeill, 2020; Penuel et al., 2022; Sezen-Barrie et al., 2020). This dissertation extends this body of work by incorporating funds of knowledge more specifically into the framework for analysis.

Further, an implication for both research and practice is the following: The findings reinforce previous findings that when students see a connection between science learning and their lived experiences outside of school, they see science as being meaningful for their lives outside of school (Barton, 2001; Calabrese Barton & Tan, 2020; Upadhyay, 2006).

However, these findings reinforce prior literature that have problematized the NGSS as simply another set of standards documents that suggest students be “doers” of science, so long as they are doing the science that is outlined in the standards (Berland et al., 2019; Lowell et al., 2020; Miller et al., 2018). Students’ ideas and questions were not frequently the basis of investigations in class and enactment of epistemic agency only went so far as eliciting student ideas that were recognizably aligned to the standards. I echo prior calls that there must be more research done on whether or how opportunities are provided for students’ home and community-based intellectual resources to be seen as valuable science work in the context of NGSS implementation (Berland et al., 2019; Miller et al., 2018).

The third major implication of this dissertation is for practice: This study gives a greater understanding of teachers’ approaches to teaching diverse learners within the context of science education, especially considering that science education reforms call for actively engaging students in science practices (Ko & Krist, 2019). Findings highlight the real challenges that teachers face to enact epistemic agency in the context of standards and state assessments despite seeing the value of engaging students’ epistemic agency and funds of knowledge. One such challenge was a lack of curriculum materials to support teachers in engaging students’ epistemic agency; future work should continue to examine the affordances and constraints of curriculum in this regard (Lowell et al., 2020). The study in this dissertation expands on this previous work by including a larger sample of specifically middle school teachers, with varying teaching experience and content knowledge. This study also includes several different data sources from both students and teachers to try to capture their rich experiences in the classroom. Further, in the current study, I did not examine any one specific curriculum, but rather how teachers' instruction draws on epistemic agency in the context of a standards implementation endeavor.

In summary, this dissertation makes a case for the importance of integrating epistemic agency and funds of knowledge approaches to avoid epistemic injustice or epistemic oppression. Redistributing power and opening up the dialogic space in the classroom for student participation is thus incredibly important for expanding diverse students' participation in the practices of science.

E. Limitations and Future Directions

As with any study, there are limitations. First, in terms of instrument design and data collection methods, both the student and teacher surveys were lengthy, and this led to participant fatigue. In particular, there were five additional questions that were included in the student survey to measure funds of knowledge but because they were included at the end of the survey and participants were so fatigued, the data were unusable. There were 12 additional questions at the end of the teacher survey that were intended to measure funds of knowledge that had such large amounts of missing responses that the data were unusable as well. As such, these items had to be excluded from analysis. This also limited the kinds of analyses that were possible to do with the data. For the purposes of this study, however, enough items had sufficient data for descriptive analysis (for both surveys) and statistical analysis (for the student survey) to answer the research questions. It is important to note that the epistemic agency and funds of knowledge items that were included in this analysis were in the first half of the survey (lending more evidence that these items had sufficient data because they were not at the end of the survey when participants were fatigued). The items that were included in this study for each construct (and that can be found in the Appendix) had no more than 10% of the data missing. Future work should consider survey length as a potential barrier to data collection due to participant fatigue; this study could have been strengthened by including these items in the analysis.

Furthermore, it is important to note that the items meant to measure funds of knowledge and epistemic agency were different for student and teacher surveys. This limited the kinds of claims that could be made about comparisons between student and teacher responses. However, items were similar enough to answer the third research question about student and teacher survey comparisons. Additionally, students and teachers were asked at the end of the academic year to reflect on instruction over the course of an entire year which could present limitations due to human error and memory recall.

Additional limitations were not connected to the survey per se. It is important to note that classroom observations were not video recorded, which could mean researcher bias influenced the classroom data. To help address this limitation, an observation protocol was developed, which can be found in the Appendix. Third, 19 teachers is still a relatively small sample size and, further, all 19 teachers were from California. This limits the generalizability of the work. There were additional teachers from these same six districts who did not participate in interviews and observations but who did respond to the teacher survey. Future work will look at these survey-only teachers to include a larger sample to conduct statistical analyses. Future work will also include analyzing more data as sources of evidence or additional findings; the larger project study conducted end-of-year interviews with teachers that were separate from the classroom observations. There were questions in these interviews that asked specifically about epistemic agency and future work will analyze these responses to further refine findings for this study's research questions. Furthermore, in this study, I grouped teachers by their district and not by their personally reported professional learning hours; future work will group these teachers by reported professional learning hours to see if this changes the findings.

Lastly, there are limitations regarding my own knowledge about the professional learning that was offered to teachers in extensive support districts. I did not participate in the professional learning myself and as such my own knowledge about what was covered in the professional learning is limited.

F. Conclusion

It is important for research and practice to identify how to support teachers in enacting student epistemic agency, given the call put forth in science education reforms like the NGSS to engage students in the process of sensemaking. There needs to be greater understanding about what effective strategies teachers use to teach diverse learners within the context of a reform-oriented science education landscape that calls for actively engaging students in science practices. Teachers need to be supported in more fully drawing on students' funds of knowledge to encourage student epistemic agency.

As found in this study, when teachers were frequently implementing epistemic agency, they were also frequently implementing funds of knowledge. However, when teachers were not frequently implementing epistemic agency, they could be frequently implementing funds of knowledge. Student reports disagreed somewhat with teacher reports about how frequently they were engaging in the SEPs and engaging in lessons that drew on their funds of knowledge; students whose teachers rated themselves high reported less frequency of implementation for both constructs than students whose teachers rated themselves low or medium.

However, closer qualitative analysis of two exemplary teachers, Stacy and Katie, showed that teachers were engaged in collectively learning from each other and that students actively sharing their ideas was considered a class norm. Taken together, findings highlight how, through collective contributions from students and teachers, students are guided to take cognitive responsibility for their learning by drawing on their funds of knowledge to make sense of phenomena. There are several positive outcomes when students are empowered and supported to take on cognitive responsibility: They come to see themselves as scientists and science people, they are apprenticed into the science practices, they better understand science as a coherent discipline, and they are given more power in the classroom, which is of special importance to diverse learners. When teachers and researchers respect the intellectual work that happens outside the classroom as both valid and valuable knowledge for in-class investigation and discussion, students are engaged to be powerful actors in the classroom and active contributors to the collaborative work of science.

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Appendix

Teacher End-of-Year Survey Items of Interest (2018-2019 and 2019-2020)

Epistemic Agency Questions:

1. Thinking about your science instruction over the entire year, how often did you have students do each of the following? (Response scale: Never Rarely - for example: A few times a year, Sometimes - for example: Once or twice a month, Often - for example: Once or twice a week, All or almost all science lessons)

   a. Determine whether or not a question is "scientific" (meaning it requires an answer supported by evidence gathered through systematic investigation)

   b. Generate scientific questions based on their curiosity, prior knowledge, careful observation of real-world phenomena, scientific models, or preliminary data from an investigation

   c. Determine what data would need to be collected in order to answer a scientific question (regardless of who generated the question)

   d. Develop procedures for a scientific investigation to answer a scientific question (regardless of who generated the question)

   e. Conduct a scientific investigation (regardless of who developed the procedures)

   f. Organize and/or represent data using tables, charts, or graphs in order to facilitate analysis of the data

   g. Compare data from multiple trials or across student groups for consistency in order to identify potential sources of error or inconsistencies in the data

   h. Analyze data using grade-appropriate methods in order to identify patterns, trends, or relationships

i. Consider how missing data or measurement error can affect the interpretation of data

j. Make and support claims (proposed answers to scientific questions) with evidence

k. Use multiple sources of evidence (for example: different investigations, scientific literature) to develop an explanation

l. Revise their explanations (claims supported by evidence and reasoning) for real-world phenomena based on additional evidence

m. Develop scientific models—physical, graphical, or mathematical representations of real-world phenomena—based on data and reasoning

n. Identify the strengths and limitations of a scientific model—in terms of accuracy, clarity, generalizability, accessibility to others, strength of evidence supporting it—regardless of who created the model

o. Select and use grade-appropriate mathematical and/or statistical techniques to analyze data (for example: determining the best measure of central tendency, examining variation in data, or developing a fit line)

p. Use mathematical and/or computational models to generate data to support a scientific claim

q. Determine what details about an investigation (for example: its design, implementation, and results) might persuade a targeted audience about a scientific claim (regardless of who made the claim)

r. Use data and reasoning to defend, verbally or in writing, a claim or refute alternative scientific claims about a real-world phenomenon (regardless of who made the claims)

s. Evaluate the strengths and weaknesses of competing scientific explanations (claims supported by evidence) for a real-world phenomenon

t. Construct a persuasive case, verbally or in writing, for the best scientific model or explanation for real-world phenomenon

u. Pose questions that elicit relevant details about the important aspects of a scientific argument (for example: the claims/models/explanations, research design, implementation, data analysis)

v. Evaluate the credibility of scientific information—for example: its reliability, validity, consistency, logical coherence, lack of bias, or methodological strengths and weaknesses (regardless of whether it is from their own or others' work)

w. Summarize patterns, similarities, and differences in scientific information obtained from multiple sources (regardless of whether it is from their own or others' work)

x. Act on a science issue/topic to address it in their school or community

2. Thinking about your science instruction this year, how often did the following activities take place? (Response scale: Never Rarely - for example: A few times a year, Sometimes - for example: Once or twice a month, Often - for example: Once or twice a week, All or almost all science lessons)

a. Teacher explaining a science idea to the whole class

b. Teacher conducting a demonstration while students watched

c. Whole class discussion

d. Students working in small groups

e. Students completing textbook/worksheet problems

Funds of knowledge questions

1. Thinking about your science instruction over the entire year, how often did you incorporate the following? (Response scale: Never Rarely - for example: A few times a year, Sometimes - for example: Once or twice a month, Often - for example: Once or twice a week, All or almost all science lessons)

a. The real-life applications of science
b. The real-life applications of engineering
c. The connections between science disciplines (e.g., earth/space, life, physical) and how they work together
d. The connections between science and engineering and how they work together
e. Encouraging students' interest in science and/or engineering
f. Developing students' awareness of STEM careers
g. The connections between students' prior knowledge or experiences to what is done in science class
h. The connections between things in students' everyday lives to what is done in science class
i. Providing science instruction that is based on students' ideas (whether completely correct or not) about the topics you teach

2. Thinking about your science instruction over the entire year, how often did you do the following? (Response scale: Never Rarely - for example: A few times a year, Sometimes - for example: Once or twice a month, Often - for example: Once or twice a week, All or almost all science lessons)

a. Discuss students' prior knowledge or experiences related to science topics or concepts
b. Build on students' initial science ideas

c. Facilitate classroom discussions drawing on students' ideas

d. Incorporate science issues/topics that may encourage and empower students to make a change in their school or community

e. Encourage students to have a voice in co-constructing what happens in the science class

f. Incorporate real-life applications of science

g. Incorporate real-life applications of engineering

Student Survey Items of Interest (2018-2019 and 2019-2020)

1. How much do you agree or disagree with the following statements about science? (Response scale: Strongly disagree, Somewhat disagree, Neither agree or disagree, Somewhat agree, Strongly agree)
   a. Science can help me understand the world
   b. Science can help to solve problems in the world
   c. Learning science can help me in my life outside of school
   d. Listening to other students in class usually helps me improve my thinking
   e. I am usually comfortable sharing my ideas with my science class

2. How often has your science class investigated questions or problems about the following? (Response scale: Never, Not much, Sometimes, A lot, I don't know)
   a. Something in my community
   b. Something going on somewhere else in the world
   c. Something from a textbook, worksheet, or other material the teacher gave me
   d. Something that didn't make sense to me, and I couldn't figure it out
   e. Something that my class and/or I saw (either in person or in a video)
   f. Something that is interesting to me
   g. Something that has happened to me or others in my class
   h. Something going on at home

3. How often has your science class investigated questions or problems asked by the following? (Response scale: Never, Not much, Sometimes, A lot, I don't know)
   a. The teacher
   b. You
   c. The class
   d. Your small group
   e. The book or worksheet

f. Your community

4. What we do in science class… (Response scale: Strongly disagree, Somewhat disagree, Neither agree or disagree, Somewhat agree, Strongly agree)

a. Matters to me

b. Matters to the class

c. Matters to the community

d. Matters to my teacher

e. Doesn’t matter to anyone

Pre-Observation Interview Protocol (2018-2019)

Background/Context Information

1. **[NEW TEACHERS ONLY]** Please give a brief introduction of yourself.
    a. What is your background (college major, teaching credential, teaching experience, etc.)?
    b. How would you describe your school and district context (what is the demographic makeup/culture of your school and how does this compare to your district)?
    c. What is your current position (what do you teach and who are your students)?
2. **[RETURNING TEACHERS ONLY]** Has your position changed since last school year?
3. **[RETURNING TEACHERS ONLY]** Has your school and/or district context changed since last school year?
4. Tell me about the class we're going to observe.
    a. How many students are in this class?
    b. Do you have a seating chart you can share with me?

General Overview of the Lesson (*brief description of what it is the students will be doing*)

So now I would like to ask you about the lesson that I will be observing.

5. What is the science lesson about?
6. Is there anything you can give me, like a lesson plan, to help me prepare for and follow along during the lesson?

Lesson Planning & Preparation Process

Please walk me through the process you used to prepare to teach this lesson.

7. Where did this lesson come from?
8. Have you made any changes to the lesson?
    a. [If yes] What changes did you make?
    b. Why did you make those changes?
        i. How do you think those changes will affect how the lesson goes?
9. Did you plan and prepare for this lesson similarly to how you normally do? Please explain.

Goals & Anticipation of the Lesson

10. What are your goals for the lesson?

    a. What do you hope students will learn during the lesson?
    b. What do you hope students will produce by the end of the lesson?
11. How do you expect the lesson will go?
    a. What will you look for to determine how well the lesson goes?
    b. How do you expect students will engage with lesson activities?
12. Is there anything in the lesson you think the students might be challenged by? Please explain.
13. What parts of the lesson do you think align with NGSS and why?
    a. What are the main DCIs that are a part of your lesson?
    b. What are the main SEPs that are a part of your lesson?
    c. What are the main CCCs that are a part of your lesson?

Coherence **(within unit or lesson sequence)**

Now I have a few questions about the lesson sequence or unit the lesson is a part of.

14. How would you describe the overall storyline or sequence of the unit that the observed lesson is a part of? [Probe for science concepts/DCIs, Practices/SEPs, and connections/CCCs]
    a. How does the observed lesson fit within the unit?
        i. How does this lesson build on previous lessons in the unit or other units?
        ii. How does this lesson connect to future lessons in the unit or other units?
15. Is the unit structured around a central question or phenomena?
        i. [If yes] What is it?
        ii. Are there other questions/phenomena that are also investigated/explored in this unit?
16. During the lesson I will observe, what prior knowledge, practices, or experiences do you hope that students make connections to?
    a. How will the lesson or your teaching practices support students to make those connections?

Integrated Science Model/Engineering

17. How, if at all, does this lesson involve integrating science disciplines? What about the unit surrounding this lesson?
18. How, if at all, does this lesson involve engineering?
19. How authentic do you think students’ experiences with science and engineering are in this lesson?

M*id-Observation Interview Protocol (2018-2019)*

[To be used after Day 1, before the unit continues on Day 2]

1. How do you feel the lesson today went?
2. During the lesson I observed today, what (if any) changes did you make?
   a. **[If applicable]** Why did you make these changes?
3. Did you observe any students having trouble with any parts of the lesson?
   a. [**If yes**] Where?
   b. [**If yes**] Why do you think the students struggled with these parts of the lesson?
4. In today's lesson, describe how you think the students may have directed/guided their own learning.
   a. Please provide an example from today if possible.
   b. Was having students to direct their own learning intentionally planned in today's lesson?
5. Do you think students were able to connect the lesson to their everyday experiences and lives outside of school?
   a. Why (or why not)?
6. Please provide a brief overview of the lesson I will observe [**tomorrow**].
   a. What do you expect students to be doing during the next lesson?
   b. What (if any) changes do you plan to make?
      i. **[If applicable]** What were students doing today that led you to make changes for [**tomorrow's**] lesson?

Post-Observation Interview Protocol (2018-2019)

General Overview of the Lesson

1. How do you think the lesson went today?

    a. How do you think the lesson went compared to what you expected?

        i. Was there anything that surprised you?

        ii. Did you do anything different than you anticipated?

            1. Why did you decide to do something differently?
            2. What impact do you think that action had on students? Why?

        iii. Did the students do anything different than you anticipated? Did they take on the role you anticipated them to take on?

            1. How did you address this change in the moment?

        iv. Describe how you think the students may have directed/guided their own learning.

2. [If the teacher taught the lesson before] How did it go this time compared to when you taught it in previous years/periods?

    a. [If teacher gives short answer]

        i. "Why do you think it went OK?"

        ii. "What makes you think that?"

3. How was the students' engagement compared to what you expected?

    a. What about the amount of students' engagement?

    b. What about the type of engagement you saw from students during the lesson?

    c. What from the lesson today makes you think that students were engaged in that way?

4. Do you think you achieved your original goals for the lesson? Why or why not?

    a. What from the lesson today makes you think that you achieved your goal(s)?

Sequence and Connections in Unit

5. What do you plan to do with this class after today's lesson?
    a. Make sure to explicitly probe about loose ends you observed during the lesson.
        i. E.g. if no conclusions were drawn from the data in the lesson, you could explicitly ask "do you have any plans to discuss takeaways from the observations students shared during today's lesson?"
6. Does what happened in the lesson today affect your plans for the rest of this unit?
    a. Describe what happened that makes you want to change.
    b. How are you going to go about making this change?

NGSS Themes in Unit

7. Was this a typical lesson for you? How is it similar or different from your typical science lessons?
    a. Probe for differences in teacher actions, or differences in the structure or planning of activities

Data Integrity

8. How representative is this lesson of your classes in general?
    a. Of this class specifically? Is that different than your classes in general?
    b. Is your teaching affected depending on the following factors:
        i. Content
        ii. Students in class
        iii. Type of lesson
        iv. Other factors
9. Do you think my being here affected students' reaction to the lesson? Why or why not?
    a. Did you notice anything in the lesson that I may have overlooked?
    b. Is there anything I can do to make my presence in the classroom less intrusive?

Description of Lesson Activities

[DAY 1 of observation]

Time	Description	Researcher Notes

**** DON'T FORGET: must do mid-observation interview with teacher BEFORE day 2 of observation****

[DAY 2 of observation]

Time	Description	Researcher Notes

Overview of Lessons

Fill in the following table to provide a brief description of the structure and flow of the two lessons. Provide approximate times spent on different lesson activities (length in minutes), their participation structure, and the main activities. Create a new row for each portion of the lesson. It should not contain identifiable information (e.g., names). Bold the main activities (see example in first row below) in the description. Participation structure can include whole class, whole class discussion, small group, and individual work.

DAY 1		
Time	**Participation Structure**	**Description of Main Activities**
5 minutes	*Whole class discussion*	*Students talk (facilitated by the teacher) about **last night's homework on cells**.*
DAY 2		
Time	**Participation Structure**	**Description of Main Activities**
5 minutes	*Whole class discussion*	*Students talk (facilitated by the teacher) about **last night's homework on cells**.*

Instructional Materials

****Instructional Materials used** *[if known]*:

- ☐ Textbook (try to take a picture of the book; include title):
- ☐ Online material (insert link/upload in data):
- ☐ Early Implementers-developed
- ☐ District-developed
- ☐ Teacher-developed
- ☐ Other (describe):

**if selected more than one instructional material, please specify below how they were used, and which parts of the lessons used which instructional materials (if applicable)

Physical Classroom Environment

Classroom layout [indicate which pictures show classroom layout; describe general set-up below]:

Describe the amount of **classroom space** the lessons took place in, and whether it appeared to be **adequate** for the number of students and/or activities in the lessons:

- ☐ NOT adequate space for the number of students and/or activities observed
- ☐ Adequate space

Describe why you selected the above about adequacy of classroom space:

Describe the **room arrangement,** focusing on how the arrangement supported or inhibited tasks in the lesson activities, and interactions among students

- ☐ NOT supportive (i.e., inhibited) lesson activities and/or interactions among students
- ☐ Supported lesson activities and/or interactions among students

Describe why you selected the above about room arrangement:

Specific NGSS Elements Present

Which **science disciplines** did you observe during the lessons? [check all that were present]

- ☐ Earth Science
- ☐ Space Science
- ☐ Life Science/Biology
- ☐ Physical Science (Chemistry)
- ☐ Physical Science (Physics)

Describe the MOST OBVIOUS **anchor** and/or **investigative phenomena** used in the lessons (or larger unit if known from interviews) *[write "N/A" if none observed/known]*

Anchor Phenomenon: [[insert anchor phenomenon here]]

Investigative Phenomenon 1: [[insert investigative phenomenon here]]

Investigative Phenomenon 2: [[insert investigative phenomenon here]]

Which **parts of the NGSS** visions of science classrooms that are **NOT** included in our framework appeared to play an important part in the observed lessons? [check all that were present]

- ☐ Computer Science
- ☐ Environmental Science
- ☐ Technology Integration
- ☐ 21st Century Skills
- ☐ Student Discourse
- ☐ Assessment
- ☐ Instructional Materials
- ☐ OTHER: [please describe]

Additional Information

Data Collection Decisions and Limitations:

What other information would be important for understanding the context of the lessons (e.g., lesson interruptions, last-minute modifications due to weather or access to resources, timing in the school year)?