SUPPORTING URBAN SECONDARY SCIENCE TEACHERS IN PROMOTING EQUITABLE SCIENCE CLASSROOMS THROUGH INCLUSIVE THREE-DIMENSIONAL INSTRUCTION

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ABSTRACT

SUPPORTING URBAN SECONDARY SCIENCE TEACHERS IN PROMOTING EQUITABLE SCIENCE CLASSROOMS THROUGH INCLUSIVE THREE-DIMENSIONAL INSTRUCTION

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This dissertation is composed of three studies focused on supporting teachers in promoting equity in science classrooms through inclusive science instruction. The National Research Council describes inclusive science instruction as a collection of strategies used to engage students in science. In study one, I propose a reframing of inclusive science instruction by examining the literature in science and multicultural education, and identifying five essential elements of inclusive three-dimensional (3D) science classrooms. I envision this reframing as moving beyond strategies for including disengaged students, and as one crucial step in promoting equity. I worked with five content experts to establish validity and reliability for *The Framework for Inclusive Three-dimensional Science Classrooms* and provided clarification of Framework elements with teaching examples from two veteran urban high school science teachers. This reframing of inclusive science instruction serves as an important pedagogical shift for teachers by drawing in social, cultural, and emotional aspects of learning into science classrooms.

Supporting teachers in transitioning to 3D instruction while meeting the needs of all students will require sustained support, and time to adapt. In study two, I use *The Framework for Inclusive Three-dimensional Science Classrooms* as a guiding pedagogy for supporting teachers in transforming their teaching. I explore the aspects of a sustained Professional Learning Program (PLP) teachers engage with and how they enact their learning in the classroom. To conduct this study, I first developed a research-based, year long PLP focused on integrating

inclusive teaching practices with 3D instruction. Five teachers from the Los Angeles Unified School District (LAUSD) participated in the program while implementing a 3D physical science curriculum in their classrooms, and I selected three teachers for case study analysis. Findings indicate that each teacher engaged with different aspects of the PLP to make changes in instruction that supported their students, and their own goals for instructional change.

Teachers need quality curricular materials that support 3D learning, and knowledge of instructional approaches that provide learning opportunities for all students. In study three, I explore how inclusive 3D instruction supports teachers in implementing project-based, 3D science curriculum in ways that supported their particular students. Five teachers from LAUSD participated in a year long PLP focused on inclusive science instruction, and two teachers were selected for case study analysis. Findings indicate that both teachers integrated inclusive instructional techniques with project-based learning very differently and did so in ways that met the individual needs of their students and context.

An important takeaway from this work is that teachers – just as students – enter learning programs with a wide range of identities impacting how and what they learn, and what that learning looks like in practice. As such, effective PLPs must be responsive to teacher's contextual needs and goals, and provide space for teacher exploration and interpretation of ideas. While the ultimate goal of effective PLPs is to effect student learning outcomes, it is important to remember that providing teachers with spaces where they are valued and respected is just as important. We can value and respect teachers by providing PLPs where teachers' ideas are valued, where teachers have opportunities to learn in ways they prefer, and where they are given the freedom to make instructional decisions as professionals.

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KEY TO ABBREVIATIONS

3D	Three-Dimensional - Three-dimensional Learning or Instruction.
CC	Crosscutting Concepts
DCI	Disciplinary Core Ideas
DQB	Driving Question Board
EQuIP	Evaluating the Quality of Instructional Products
ELL	English Language Learners
LAUSD	Los Angeles Unified School District
NGSS	Next Generation Science Standards
NRC	National Research Council
PBL	Project-based Learning
PLP	Professional Learning Program
SEP	Scientific and Engineering Practices

CHAPTER 1: INTRODUCTION

This work started for me long before graduate school, when I was working full time as a science and engineering teacher at an urban[2] high school in a large city. I found my first few years as a teacher difficult (as most teachers probably do), and it took time for me to integrate into the school community and flourish as a teacher. Reflecting back, I think one thing that really helped me grow was volunteering as the school's robotics coach. My first few years as a coach were also tough (I knew nothing about robotics when I started) but it became my passion and to my delight, I noticed robotics spilling over into everything else in my life. It was through coaching robotics that I had the opportunity to interact with students as a mentor or coach rather than only as a teacher who assigns a grade – something that changed the nature of my student interactions, and our relationships in the classroom. I met a lot of family and community members who either had students on the team, or were excited about our work and wanted to help out. It was coaching robotics that helped me realize the importance of participating in a school community, and that leveraging community assets was important for everyone.

Working with students and their parents over multiple years was a rewarding experience, and one where I learned a lot about students, myself, and the nature of education. One experience that I think about often took place during my second-to-last year of coaching and teaching. I was working with a small team of about five students – so we got to know each other very well. They were a highly motivated team, and worked hard to prepare themselves for competition. That year we ended up making it to the national championship, and I fondly remember squeezing into a van and driving to the center of the country – Omaha, Nebraska – to compete with teams from all over the United States. However, that is not the experience that stays with me. It was the state competition held at a neighboring high school about an hour from our school. We met at the

[2] Large, city school full of students with rich knowledge, histories and backgrounds that do not always receive the quality of education they deserve due to fiscal and political constraints.

school that day and drove to their campus. When we arrived at the school, I appointed one of the students as a navigator. The high school complex consisted of multiple buildings and resembled a small college campus. After some twists and turns, we finally pulled up to the front of the school, which was gigantic and beautiful. Ten large columns adorned the front of the building, and one of the students exclaimed from the back "wow, it looks like the white house!" and it did.

Everything about this school seemed different from ours, and all day the students couldn't help but make comparisons. The floors were new with no scratches, the ceilings didn't have cracks, there was no mold behind the drinking fountains, and their gym was large enough to host a state robotics competition. This conversation made me uneasy, but I didn't know what to say. For many of them, this was their first experience visiting a wealthy suburban school. Later that afternoon when we took a team bathroom break, the students were again amazed at the experience. In the girl's bathroom, the students started laughing and exclaiming at how different everything was. "Can you believe they have soap in here?" one exclaimed "and paper towel!" The restrooms were clean, unlocked, and all of the stalls had toilet paper – a very different experience than at our school where students requested toilet paper from a teacher and asked the security guard to unlock the bathroom each time they needed to use it. It was at "toilet paper" where the students stopped giggling and the conversation took a serious turn. The girls were genuinely curious. Why was this high school so different? Why couldn't they have toilet paper and soap in the bathrooms at school too? It's toilet paper - how expensive can it possibly be? We talked for a while in the hallway about the differences between the two schools, and why they might be so different. This experience has always stayed with me – although at the time I couldn't articulate why.

After reflecting, I realized what stood out to me in this situation wasn't that our school had less than their school, but the hidden message that students received every time they asked a teacher for toilet paper or to unlock a bathroom. The message is one of inconvenience rather than one value and respect. It made me think about how this message impacted their lives and their learning, and about how important it is show all students how important they are. Over the years I have come to realize the systemic issues that contribute to inequities in education do not happen overnight, and will require scholars and stakeholders from different backgrounds working together to make a change. My thinking is consistently focused on promoting equity within classrooms, particularly on the interactions between teachers and students, and how teachers can provide equitable opportunities for all of their students to learn science. Many scholars before me have also focused on classrooms and have taken up "equity in classrooms" in different ways. Recently, I have come to think about equity as being inherently nested within existing structures. For example, equity in classrooms is an important aspect of equity in schools, which may also be a fragment of equity in communities, the workforce or the academic disciplines. I have come to think of equity in classrooms as more than just providing students with opportunities to learn in science, but also as a social justice issue in that students should be supported in developing the skills and tools they need to identify and address inequities they may experience in their daily lives.

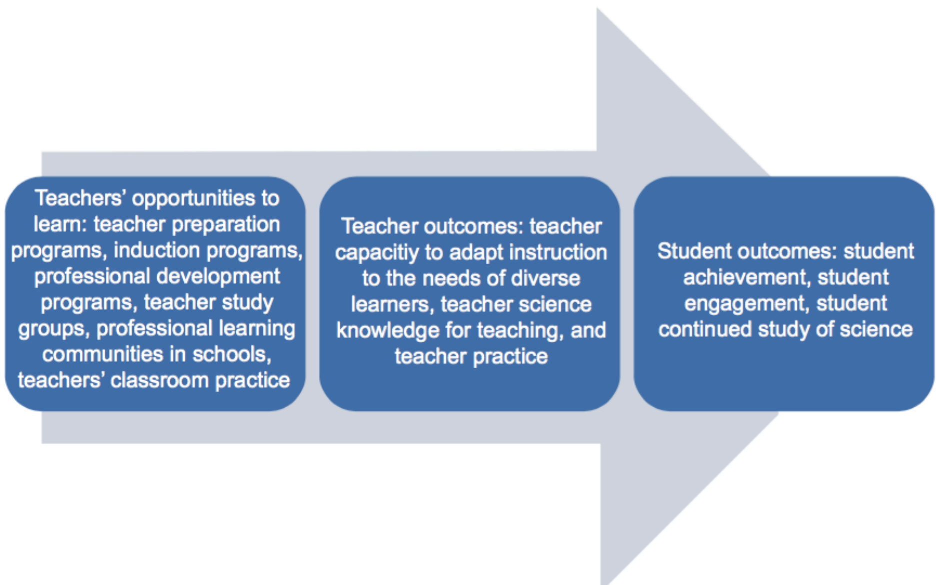
My personal brand of equity draws from Felicia Moore Mensah's agenda for diversity, equity, and social justice. She describes teaching and learning of science as a civil right, a moral obligation, a social responsibility and an ethical choice (Mensah, 2013). Further, "the science teacher embraces the belief that every child has a right to learn science, deserves free access to science, is empowered by knowing science, and is provided opportunities to advance himself or herself educationally within science" (Mensah, 2013 p. 320). Also contributing to my concept of equity in classrooms are the writings of scholars like Geneva Gay, Gloria Ladson-Billings, and many others. Ladson-Billings defined culturally relevant teaching as a pedagogical approach that empowers students intellectually, socially, emotionally and politically (1994). Gay describes culturally responsive teaching as a pedagogical shift that teaches "to and through" personal and cultural strengths of students (2000). Equity in classroom requires teachers to learn from their students and teach *with* them rather than *to* them. It also requires teachers to provide students with equitable learning opportunities that honor and value student's unique identities and backgrounds, and helps students identify and dismantle structural barriers to success within the classroom, and beyond.

As a science educator, I was intrigued by the National Research Council's (NRC) Framework for K-12 Science Education. The vision described for engaging students in three-dimensional (3D) learning was different than the previous science standards. Under the old standards, I was given a list of all the things students should know by the end of the semester, with a textbook and a set of slides to aid in my instruction. However, 3D instruction is centered around engaging students in scientific and engineering practices (SEPs), such as asking questions, and constructing explanations, disciplinary core ideas (DCIs), which are big ideas in science that explain a range of phenomena, and crosscutting concepts (CCs), ideas that cut across disciplines including cause and effect and identifying patterns (NGSS Lead States, 2013; NRC, 2012). Although I didn't explicitly see my vision for equity in classrooms fully expressed in this new Framework for science education, I do see openings for teachers to provide all students opportunities to learn science within the 3D learning Framework. The switch for teachers from traditional science instruction to 3D instruction will be a major challenge for some teachers, and researchers identify that this transition will require extensive support (NRC, 2015; Reiser, 2013). If science teachers across the country will already require professional support for the transition to NGSS, then integrating practices that support equity in classrooms with the three dimensions could be a powerful way to transform education and work towards equitable science classrooms across the country.

A Dissertation in Three Parts

This dissertation consists of three studies focused on supporting teachers in integrating teaching approaches that value and support all students in science learning. Wilson emphasizes that professional learning programs provided to teachers are often disjointed and incoherent, not aligned with curriculum, and rarely sustained over time (Wilson, Rozelle, & Mikeska, 2011). My goals for this dissertation were to develop 1) a well-defined Framework describing inclusive science instructional pedagogy, 2) a sustained and coherent professional learning program with ample supports for teachers, 3) an analysis of the usefulness of my Framework, and it's impact on teacher learning when presented through a research based professional learning program, and 4) an analysis of whether the instructional approach I propose supports teachers in integrating their instruction with the goals of a project-based learning curriculum. I used Figure 1.1 as a guide to consider the importance of this work and the broader impacts of my dissertation. Figure 1.1 is taken from *Science Teachers' Learning: Enhancing Opportunities, Creating Supporting Contexts* which links learning opportunities provided to teachers with teacher learning outcomes, and then to student learning (Wilson, Schweingruber, & Neilsen, 2015). The three studies that comprise this dissertation (described in detail below) aim to follow this trajectory by providing professional learning opportunities for teachers in integrating practices that promote equity in science classrooms - as a means to impact teacher learning - in hopes that students will also benefit from this work. It is important to note that all of my research is focused on teacher learning and implementation of curriculum and pedagogy, but the impact of this work on students and student learning is never far from my mind.

Figure 1.1: Linking teacher learning opportunities, to teacher learning, to student learning



Reprinted from Wilson, S. M., Schweingruber, H. A., & Nielsen, N. (Eds.). (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/21836

The first study titled: "Reframing Inclusive Science Instruction to Support Teachers in Promoting Equitable Three-dimensional Science Classrooms" outlines five elements that support the development of classrooms where all students feel valued, comfortable, and confident sharing ideas. I use the term inclusive here because I believe the practices outlined in this Framework are collectively an important stepping-stone to promoting equity in science classrooms. In this study, I consult the literature in both science and multicultural education to outline five elements that integrate ideas promoting inclusive classrooms with the vision of three-dimensional instruction outlined by the NRC. My hope is that this Framework will challenge science educators to consider inclusive science instruction as more than just a collection of strategies for non-dominant students, but as a guiding Framework for teaching philosophy and practice for all teachers in all contexts. The elements described here rely heavily on funds-of-knowledge as a conceptual tool to guide instruction. Funds-of-knowledge has been defined as "the historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being" (Moll, Amanti, Neff, & González, 1992 p. 133) and can be an important conceptual tool for teachers. Considering funds-of-knowledge as a conceptual tool requires teachers to position themselves as learners with their students rather than experts, and understanding students' cultural backgrounds gives teachers greater opportunities to adopt practices that authentically engage their students in science (Calabrese Barton, Tan & O'Neil, 2014).

Drawing on funds-of-knowledge as a conceptual tool, I developed five practices that guided my professional learning work with teachers. These include: 1) Positions students as knowledge generators, 2) Elicits, values, and leverages funds-of-knowledge, 3) Encourage use and sharing of student language, 4) Valuing students' lived experiences as evidence, and 5) Promoting use of students' critical lens to solve problems. After development of the Framework was complete I established validity and reliability by coding with other equity-focused scholars, and then used it for observations in two classrooms to develop real-world descriptions of what each of the five practices could look like. The two teachers whom I selected for observation were veteran teachers with more than 25 years of experience working in large urban schools, who were also implementing a three-dimensional curriculum in their classrooms. I looked for examples of how each teacher integrated their expert knowledge of their students and context with the three-dimensional curricular activities. The resulting Framework became the guiding material for the professional learning program I developed for the next study.

Study two, titled: “Science Teacher Learning of Inclusive Three-dimensional Instruction Through Participation in a sustained Professional Learning Program”, focuses on providing professional learning opportunities for teachers, and examining teacher learning outcomes. In this study, I outline the development of a year-long professional learning program for teachers grounded in a curriculum aligned with the three dimensions of NGSS and explore the teacher learning outcomes of that program. My research question is 1) *What aspects of a professional learning program do teachers interact with, and how do they enact their learning in the classroom?* I selected three teachers for case-study analysis and I looked for patterns in how they engaged in professional learning sessions, and in how they integrated their learning into classroom teaching. Findings indicate that all three case-study teachers engaged with different professional learning opportunities provided during the program, and that each teacher implemented his learning into the classroom in ways that aligned with inclusive three-dimensional instruction, and met their contextual needs. Providing teachers with varied professional learning opportunities was important both for engagement in learning, but also for providing varying ways to enact that learning in their classrooms.

After determining how teachers interacted with the professional learning program and put their learning into practices, study three turns to an examination of whether implementation of inclusive science pedagogies supported the goals of a project-based science curriculum in ways that met the individual needs of the student’s context. In Study Three, titled: “Supporting Urban Science Teachers in Implementing a Project-based Curriculum Using Inclusive Three-dimensional Instruction”, I again focus on teacher learning outcomes – only this time with respect to curriculum implementation. My research question asks 1) *How does inclusive three-dimensional instruction support teachers in implementing a project-based science curriculum in ways that best meets the needs of their students and context?* For this study, I analyze classroom observation data of two teachers with respect to two of the practices defined in *The Framework for Inclusive Three-dimensional Science Classrooms*: positioning students as knowledge generators, and eliciting, valuing and leveraging funds-of-knowledge. I focus on these two practices for two reasons--they both rely heavily on funds-of-knowledge as a conceptual tool, which was also emphasized in the professional learning program, and these two practices were somewhat supported in the educative curricular materials with which teachers were working. In addition, I looked for features of project-based learning in instruction including: 1) driving questions, 2) learning goals that align with standards and assessment, 3) participation in scientific practices, 4) engaging in collaborative activities, 5) using technology, and 6) creating tangible products that address driving questions.

The three studies presented in this dissertation define a Framework for inclusive three-dimensional instruction, describe development of a sustained professional learning program for teachers, examine teacher learning of concepts presented in the program, and examine how the combination of curriculum and instruction support one another. My hope is that the combination of inclusive science teaching as a guiding pedagogy, and three-dimensional instruction can inform professional development efforts across the country as teachers and districts move forward implementing the Next Generation Science Standards. Helping teachers develop inclusive, three-dimensional classrooms is an important step to promoting equity in science classrooms, increasing opportunities for all students to learn science, and is especially important for students in contexts where fiscal or political constraints constrain equitable learning opportunities. While the current reality is that there are vast inequities between districts including lack of funding, overcrowding, and lack of supplies (Carter-Andrews, Bartell, & Richmond, 2016), *The Framework for Inclusive Three-dimensional Science Classrooms* provides teachers with a guide to ensuring all students know they are important and valued members of the school community.

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CHAPTER 2: STUDY ONE

Reframing Inclusive Science Instruction to Support Teachers in Promoting Equitable Three-dimensional Science Classrooms

Abstract

In the K-12 Framework for Science Education, the National Research Council frames inclusive science instruction as a collection of strategies for teachers to engage students in science. In this conceptual paper, I propose a reframing of inclusive science instruction by examining the literature in science and multicultural education, and describe five elements to support teachers in developing inclusive science classrooms. I established validity and reliability for this Framework by working with content experts in the field, and clarified Framework elements with teaching examples from two veteran, urban high school science teachers. Data used for Framework clarification include field notes, interviews, and video-recorded lessons. I also discuss my goal of reframing inclusive science instruction as an important pedagogical shift in promoting equitable science classrooms.

Introduction

The gap in academic achievement between dominant students (who are white, male, heterosexual, and cis-gender) and non-dominant students has been widely publicized in educational literature and is an important focus for education research (Ladson-Billings, 2006). Public schools were designed in part as “the great equalizer” of society, but non-dominant students in urban settings are often not provided the same opportunities as their white counterparts in other districts. Students in urban communities often attend underfunded schools with lack of supplies, overcrowded classrooms, and unsafe building conditions, limiting teachers’ ability to teach as well as students’ opportunities to learn (Carter Andrews, Bartell, Richmond, 2016; NCES, 2012). The term “urban” often takes on a deficit perspective – a belief that students who do not meet the expectations and standards in school are less capable than their peers – by focusing on the shortcomings of students, families and communities rather than on the disparities in learning opportunities available to students (Calabrese Barton, Tan & O’Neil, 2014). For this reason, scholars argue the term “achievement gap” does not sufficiently describe these academic disparities, and instead they frame the issue as an “opportunity gap” (Milner, 2010; Quinn, 2015). By acknowledging that the gap in academic achievement results from disparities in educational opportunity, stakeholders must adopt asset perspectives of non-dominant students and communities. Similarly, researchers highlight the importance of reframing urban science education not as a problem in need of fixing, but as contexts that offer rich possibilities (Calabrese Barton, Tan & O’Neil, 2014). I take an asset approach to my research and aim to improve science education by building on the rich knowledge and history teachers and students within urban communities bring to the classroom.

The disparate opportunities to learn science between dominant and non-dominant students are a direct result of inequities in the education system, and particularly in science. For example, opportunities for non-dominant students to succeed in STEM (science, technology, engineering and math) courses are challenged because dominant adults (typically white men) hold most STEM careers and positions as K-12 science teachers. Research suggests that white teachers have greater difficulty forming relationships with non-dominant youth (Sleeter, 2008), further impacting students' opportunities to succeed. I define equitable science classrooms as spaces where teachers position students as knowledge holders, use students' cultural knowledge to enrich instruction, and provide all students with skills and opportunities to advance themselves within science (Calabrese Barton, Tan & O'Neil, 2014; Mensah, 2013). However, it is important to remember that science classrooms exist within a larger school community and developing science classrooms that are truly equitable requires teachers, administrators, parents, and the community to hold equity as a common goal and to work collectively towards it. While considering larger issues of equity at classroom, school, community, and discipline levels are important; in this paper, I focus on how teachers can work towards equitable science classrooms by developing science classrooms that are inclusive. I define inclusive science classrooms as places where students feel safe to share and critique ideas, and where they are valued members of the science learning community. Inclusive science classrooms and equitable science classrooms are not the same thing; rather, I see teachers developing inclusive science classrooms as one important step in working with the school community to promote equity.

My research coincides with a major reform in science education introduced by the National Research Council's (NRC) *Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS) to transform classrooms by putting a focus on how students make sense of phenomena or design solutions to problems by using three-dimensional (3D) learning. Three-dimensional learning engages students in braiding together disciplinary core ideas (big ideas in science), scientific and engineering practices (how scientists and engineers study the world) and crosscutting concepts (ideas that cross all disciplines). Also reiterated in the NRC and the NGSS is an important vision for K-12 science education first introduced by the American Association for the Advancement of Science– science for all students (AAAS, 1994; NGSS Lead States, 2013; NRC, 2012). The goal of this combined vision is to provide all students with opportunities to develop useable knowledge to make sense of phenomena they experience in their world. This will require teachers to transition to a 3D instructional approach while working toward inclusive science classrooms; providing exciting opportunities, and numerous challenges for educators. The vision recommended by the NRC, paired with perspectives of science learning as community-driven (Lave & Wenger, 1991), is very different from "traditional" science teaching methods that follow a transmission model where teachers deliver instruction and students listen (Luehmann, 2007). To effectively develop inclusive 3D learning communities, all teachers will need to orient their teaching away from these traditional methods and toward 3D instruction that meets the needs of all students.

The NRC defines inclusive science instruction as a collection of "strategies and approaches that build on students' interests and backgrounds so as to engage them more meaningfully and support them in sustained learning" (NRC, 2012 p. 283) and they emphasize that these strategies can promote educational equity. Situating inclusive science instruction as a set of strategies implies that it is only useful for some students or situations; specifically, they are strategies for students who are not engaged in learning. This definition builds from a deficit perspective that positions non-engaged students as a problem to be solved with "strategies that build on their interests and backgrounds" rather than a resource to be used to transform the science learning community. Providing opportunities for all students to engage in science will require educators to dismantle deficit perspectives, acknowledge the social and cultural dimensions of science, and work toward inclusive science classrooms where students feel safe to share and critique ideas that they need and value in the science classroom (Mensah, 2013; Lave & Wenger, 1991). This conceptual paper reframes inclusive science instruction not as a collection of strategies to use when needed, but as a guiding Framework for all science teachers to use in transforming their classroom communities. I worked with other scholars in the field to establish validity and reliability for this Framework, and I provided clarification of Framework elements with teaching examples form two veteran urban high school science teachers in two different areas of the United States. Artifacts from classroom observations were used to clarify the Framework and included field notes, interviews, and video-recorded lessons. My goal is to reframe inclusive science instruction in order to promote equity in science classrooms and increase opportunities for non-dominant students in science.

Conceptual Framework

A Vision for K-12 Science Education

The National Research Council describes a major recommendation for supporting student learning by building science education around three dimensions: Scientific and engineering practices (SEP), Crosscutting concepts (CC), and disciplinary core ideas (DCI) (NRC, 2012). SEPs refers to the activities scientists and engineers engage in as part of their work such as asking questions, constructing explanations, engaging in argumentation and designing and carrying out investigations. CCs refer to a series of fundamental concepts cutting across disciplines and providing a common lens for exploring phenomena; these include, for example, cause and effect, systems and system models, and identifying patterns. DCIs refer to big ideas specific to a discipline and that help to explain a range of phenomena important to the discipline. Integrating all three dimensions so students are engaged in them simultaneously is referred to as 3D learning (NRC, 2012). Using the three dimensions to make sense of phenomena and find solutions to problems will support learners in developing practical knowledge that they can use throughout their lifetime.

Together, the NRC and the NGSS present a new vision of the scope and nature of K-12 science education whereby students develop an integrated understanding of scientific content by using the three dimensions to explore meaningful phenomena throughout their education. For many teachers, implementing 3D teaching will require a pedagogical shift as 3D learning moves away from learning numerous content ideas quickly to engaging students in making sense of phenomena. Effective implementation of these standards requires teachers to adopt pedagogies quite different from the more traditional modes of instruction, which characterizes much of science teaching (Reiser 2013). For many teachers, this transition will not be easy, and the movement toward 3D teaching will likely be incremental and require sustained support (NRC, 2015).

Examining how teachers successfully scaffold 3D learning, and developing tools to help them provide opportunities for non-dominant students will in-turn promote equity. While the NRC frames equity in terms of "equal treatment of all" (p. 278) and providing all students with fair opportunities to learn (NRC, 2012 p. 282), my vision provides each individual student with the opportunities needed to be successful – which may not result in "equal treatment." I aim to support teachers in positioning students as knowledge builders, using their cultural knowledge to enrich instruction, and providing them with skills and opportunities to learn science (Calabrese

Barton, Tan & O'Neil, 2014; Mensah, F. M., 2013). I believe the first step in working toward such an "equity vision" is helping teachers develop inclusive learning environments where students feel safe to share ideas, and that they are a valued member of the classroom learning community. One aspect of promoting inclusive science classrooms is fostering classroom culture.

Fostering Classroom Culture

Parsons and Carlone define culture as "a context and time dependent phenomenon that exists on multiple planes – local, global, micro, macro, historical, and contemporary to name a few" (2012, p. 2). One potential barrier to developing inclusive science classrooms arises from the fact that many teachers come from different communities than the students they teach and may have a difficult time communicating or forming relationships with their students (Sleeter, 2008). Thus, teachers from different cultures, ethnicities, communities, countries, or even generations than their students may experience challenges in developing a science classroom community that meets their students' needs. Cultural exchanges between teachers and students, and between students and their peers are an important factor in developing an inclusive classroom. "It is a culture that defines how schools work--the way teachers and students relate to each other and the significance and value of those relationships in helping children grow" (Brown, 2002 p. 15). For teachers in contexts serving students who share their culture, these cultural aspects of teaching can be invisible. Culture lies in the expectations, values, and beliefs of teachers and students, and influences decisions, relationships, and even curriculum. For example, scholars argue that urban districts predominantly serving non-dominant students frequently base their curricula, instruction, and expectations on dominant culture (Hollins, 2012). Often, white teachers of non-dominant students don't recognize their beliefs concerning education to be a cultural response stemming from the beliefs and values shared by the dominant group (Howard, 1999). In contexts such as urban schools with large, multiracial student populations and predominantly white teachers, cultural differences are evident and can cause conflicts, which negatively impact student achievement (Sleeter, 2008). "Opportunity gaps can persist because educators' cultural ways of knowing, which are often grounded in Eurocentric cultural notions and ideologies, take precedence over those of their students" (Milner, 2010 p. 14). Teachers aiming to develop inclusive, safe classrooms where students share and critique ideas will need to acknowledge and address the cultural exchanges taking place between teachers and students, as well as between students.

Current efforts to increase student engagement in STEM classrooms often work to "create learning environments that allow non-dominant students to perform as well as their dominant peers to address the content-knowledge problem" that non-dominant students seemingly face (Bang & Medin, 2010 p. 1009). Content-based reforms are not adequate because they aim to fill student knowledge gaps rather than to critically examine social and cultural issues that inhibit academic success. Consequently, content-based reforms that target non-dominant students tend to treat learning as *acultural*, i.e., where cultural knowledge and experiences are not recognized as legitimate classroom resources (Gutiérrez & Calabrese Barton, 2015). This perspective perpetuates deficit mindsets that work--intentionally or not--to force students to adopt the traditionally accepted dominant perspectives of science (Bang & Medin, 2014). Often, this can become a self-fulfilling prophecy, with students aiming for the minimum requirements for success (Milner, 2010). This leaves non-dominant students in K-12 science classrooms with two options: assimilate to the accepted practices in science to experience success, or fulfill the expectations of deficit model thinking and disengage from the discipline.

To develop inclusive classrooms, teachers must attend to the linguistic, cultural, and emotional differences between teachers and students (Anderson, 2007). This is important in all classrooms but can be a particular challenge for teachers in urban communities serving predominantly non-dominant populations as they often feel that school science is not connected to their everyday lives or the communities in which they live (Moll & Ruiz, 2002; Tan, Calabrese Barton, Gutierrez, & Turner 2012). To help students recognize how science is connected to their everyday lives, teachers must identify how the lives and communities of their students may differ from students of the dominant cultural majority (Santoro, 2009). One conceptual tool that can help teachers bridge the gap between student communities and the classroom is funds-of-knowledge. Funds-of-knowledge – acquired by individuals over time – are bodies of knowledge and skills developed historically and which are culturally essential for life and well-being (Moll, Amanti, Neff, Gonzalez, 1992). When teachers provide opportunities for their students to leverage cultural practices from outside the classroom, it can have a powerful impact on classroom culture, student engagement, and scientific reasoning (e.g., Calabrese Barton & Tan, 2009; Calabrese Barton, Tan, O'Neil, 2014).

Integrating Inclusive Pedagogies with Three-Dimensional Instruction

In this paper, I develop a Framework for developing inclusive science classrooms based on common learning goals for science and multicultural education. I also draw upon classroom observation data to further strengthen and clarify this Framework. My intent is to use Framework elements to provide examples of practices urban teachers use to support student learning by engaging them in the knowledge generation process. In the next section, I map out the five elements comprising the *Framework for Inclusive Three-dimensional Science Classrooms*, and describe how I obtained validity and reliability for the Framework. Then, in the results, I further develop the Framework by examining the classrooms of two veteran, urban science teachers for examples of each Framework element.

Framework Element 1: Positions Students as Knowledge Generators

Ladson-Billings highlighted the importance of students experiencing academic success by developing academic skills such as literacy, numeracy, technological and social skills (Ladson-Billings, 1994). Similarly, the NRC's vision for science education includes students engaging in the eight scientific and engineering practices, focusing on a big science ideas, and using, crosscutting concepts to explore natural phenomena. Three-dimensional learning requires students to be the ones generating ideas, gathering evidence, and using evidence to explain phenomena they observe. As students engage in this process, they are generating scientific knowledge as a classroom community and using evidence to include or refute new ideas as they arise. This serves not only to aid student engagement, but also to help students experience academic success, develop important skills, and affirms students as an integral part of generating knowledge. Funds-of-knowledge as a conceptual tool "asks teachers and researchers to position themselves not as experts, but as learners with their students" (Calabrese Barton et al., 2014 p. 252). Just as the student role changes to include them as "generators of knowledge," the role of the teachers must also change. Teachers must move to a facilitator role where they are positioned as learners alongside students and allow the students authority to generate and justify or dismiss ideas based on evidence.

Framework Element 2: Elicits, Values, and Leverages Funds-of-Knowledge

Funds-of-knowledge refers to the culturally developed knowledge essential for living that students develop in their home and family life (Moll et al., 1992). Students bring this range of life experiences and worldviews to school each day, and instruction failing to acknowledge this can negatively impact student engagement and learning (NRC, 2012). Conversely, instruction building on student funds-of-knowledge integrates students into the learning process and increases engagement while affirming the importance of their experiences and cultural knowledge. In recent reviews of literature on science education in urban contexts, scholars have identified funds-of-knowledge as an important conceptual tool for dismantling deficit perspectives (Calabrese Barton et al., 2014). While some teachers express concern over taking the time to access funds-of-knowledge only helps one student at a time or takes time away from content, teachers can exercise more control over these connections by accessing different funds at different times. I also argue that drawing an individual student's funds-of-knowledge can help all students make sense of complex ideas by providing opportunities to conceptualize them in different ways. In addition, attending to student's individual learning needs, as well as the needs of the class as a group, is important for promoting equitable science learning opportunities. To do this, teachers must understand the practices of the communities in which they teach, relationships between the community and the school, and the science-related values the community holds (NRC, 2012). Calabrese Barton and Tan (2009) identify four funds-of-knowledge teachers can aim to access with their students directly linked to student learning outcomes: family funds, community funds, peer culture, and popular culture. Helping teachers adopt asset perspectives of student knowledge and understand the different types of knowledge students bring to the classroom is an important goal for promoting inclusive classrooms.

Framework Element 3: Encourages use and Sharing of Student Language

Allowing students to use their own language to explore phenomena and later transition to science language gives students time to make sense of big ideas using their own lens. The NRC recognizes that language varies across cultural groups, and the importance of encouraging students use of informal or native language (NRC, 2012). Allowing students to use their own language to describe science ideas and phenomena gives them the opportunity to see themselves in science, a necessary precursor to engaging them with the subject matter (Brickhouse, Lowery, & Schultz, 2000). Providing opportunities for students to use their language and share it with others legitimizes students' identities in the classroom while also promoting relationships and understanding (Paris, 2011, 2012). Ladson-Billings provides an example of a literacy teacher (Ann) allowing students to use home language in her book *The Dreamkeepers*. Ann encouraged the students to use home language while learning 'standard' English (Ladson-Billings, 1994). Her students were able to express themselves culturally through language while learning literacy, and were also required to translate to Standard English as they mastered literary concepts. Language is an important part of student identity, and while there is a documented achievement gap in science between racial groups, there is also an identity gap (Calabrese Barton et al., 2014). Students using their language in class to express ideas can help bridge this gap because the teacher and the classroom community accept, respect, and value who students are and what they know as necessary for forming knowledge. One caution is that teachers must be careful not to impose perceived culture on their students, but allow the students themselves to bring their language into the science classroom (Paris & Alim, 2014).

Framework Element 4: Values Students' Lived Experiences as Evidence

Engaging students in critique and argumentation helps demonstrate science as a body of knowledge rooted in evidence (NRC, 2012). In fact, science learning and understanding should grow from students' lived experiences to allow for connections between students' lives, and to provide opportunities for multiple voices and understandings to be explored (Calabrese Barton, 1998). Students' experiences are one aspect of the funds-of-knowledge that are developed and accumulated throughout a student's life. Esteban-Guitart and Moll use the term *lived experience* to emphasize that thoughts and feelings are inextricably linked, and that learning and experiences are situated within various life trajectories (Esteban-Guitart & Moll, 2014). Encouraging students to bring experiences into discussion can help them become more engaged, but it also upholds students' lived experiences as valuable evidence for learning science. Once experiences are introduced as evidence, the classroom community evaluates and determines whether the experience is appropriate to use as evidence, and whether it connects to the phenomenon. This requires an integration of disciplinary knowledge and knowledge of context so that teachers can work to mine rich experiences for use in discussion (Lee & Fradd, 1998, Johnson, 2010). Some research shows connections between children's culturally based stories and scientific argumentation (Berti, Toneatti, L. & Rosati, 2010; Zhang, Scardamalia, Reeve, & Messina, 2009), and the NRC suggests teachers should enlist student's background as a means of enhancing science learning (NRC, 2012). Allowing students to share their lived experiences affirms and values their knowledge, and can make the science classroom community more personal and meaningful for students.

Framework Element 5: Promotes Use of Student's Critical Lens to Solve Problems

Scientists engage in a constant process of critique and argumentation where they examine each other's ideas and look for flaws - practices that we also want students to engage with in 3D classrooms (NRC, 2012). Reforms in multicultural education also require students develop a critical lens and use it to solve problems, i.e., using school knowledge and skills to identify, analyze, and solve real-world problems (Ladson-Billings, 2014). In traditional science classrooms, the teacher gives students knowledge and students are expected to listen and learn it (Luehmann, 2007). This knowledge isn't questioned or critiqued by students, but accepted as fact. In contrast, 3D science classrooms are spaces where we can help students develop their critical lens by asking them to analyze situations, ask questions, poke holes in scientific arguments, question the reliability and validity of evidence, and critique and evaluate each other's work. Students can then apply this critical lens to problems in the classroom or community.

Five Instructional Features to Promote Inclusivity

Inclusive instruction requires teachers to develop a classroom that addresses the needs of all students, validates cultural identities and promotes equitable access to learning opportunities (Brown, 2004; Samuels, 2014). Many teachers may want to make a difference by providing all students what they need to be successful in science, but may simply not know how to do so. *The Framework for Inclusive Three-dimensional Science Classrooms* provides teachers with a guide designed to address opportunity gaps that are present in traditional science classrooms. Each element in the Framework requires teachers to adopt asset perspectives for their students and to use the rich knowledge, backgrounds, and experiences students bring to class to drive student learning. Each element validates that who students are and what they already know are important aspects of the science learning community. The Framework compels teachers and students to learn from and with one another as they build science knowledge together. Inclusive science classrooms promote student interest, engagement, and understanding in science by developing safe spaces for the sharing, use, and revision of countless ideas.

Validity and Reliability

To establish validity for the *Framework for Inclusive Three-dimensional Science Classrooms*, I first drew on relevant literature to establish Framework elements and met regularly with two content experts over one semester to discuss and revise the Framework. Content expert one had deep knowledge of the NGSS and three-dimensional instruction, while content expert two had deep knowledge of issues that impact non-dominant students in science classrooms. The content experts and I read, discussed, and debated each element while making revisions based on discussions. Based on their feedback, I made changes to each of the five elements over the course of one semester and developed sub-elements to describe what teachers and students would be doing to meet the criteria. For example, element one is *Positions students as knowledge generators* and I developed three sub-elements to further articulate each element: 1) Students generate and evaluate ideas using evidence, 2) Students (as a community) develop explanations through discussions and 3) The teacher consistently validates student's contributions, attributing ideas and knowledge to students, and using their ideas in discussion (see Table 2.1). These elements and sub-elements were revised in discussion with content experts one and two to ensure each element was addressing issues of both 3D learning and the needs of non-dominant students in science classrooms.

Once the Framework was revised, I met with a third content expert--a senior-level graduate student conducting research in both science and urban education. I provided content expert three with a copy of the Framework shown in Table 2.1 and written descriptions of the five Framework elements. Together, we used the Framework to analyze a lesson in the educative teacher materials to determine whether the curriculum supported these Framework elements. Once we completed analysis of this first activity together, we individually coded activities 1.2 and 1.3, for evidence of each element being supported. Our first round of coding resulted in 80% agreement in that we had almost identical curricular examples for the first four elements from the Framework, but had a different conception of what the 5th element *Promotes use of student's critical lens to solve problems* meant, and our examples from the curriculum and descriptions reflected that. After some discussion, we completed a second round of coding, using activities 1.4 and 1.5, which resulted in 100% agreement.

To establish inter-rater reliability, I met with two additional content experts and engaged in two rounds of coding. Content expert four had knowledge of the Interactions curriculum and 3D learning, but no specific knowledge of issues non-dominant students face in science. Content expert five had extensive knowledge of 3D learning and some knowledge of issues non-dominant students face in science. Similarly to validity coding, we coded activity 1.2 and 1.3 from the Interactions teacher materials. The first round of coding resulted 80% agreement with content expert four, and 100% with content expert five. Content expert four was unsure of what counted as *encourages use and sharing of student language to explore phenomena,* so after discussion we coded activities 1.4 and 1.5. This round resulted in 100% agreement for content experts four and five. Slight revisions were made as a result of discussions with both the validity and reliability groups.

Table 2.1: Framework for Inclusive Three-dimensional Science Classrooms

Framework for Inclusive Three-dimensional Science Classrooms
How well does the science teaching work to support students by valuing ideas, cultural knowledge and linguistic differences? Does the classroom work as a community to develop an environment where everyone feels safe, supported and encouraged to express ideas?
1.1 Positions students as Knowledge Generators
1.1.1 Students generate ideas and evaluate ideas using evidence.
1.1.2 Students (as a community) develop explanations by analyzing data and making decisions about whether data collected supports the phenomenon.
1.1.3 Teacher consistently validates student’s contributions, attributing ideas and knowledge to students, and using their ideas in discussion.

Table 2.1 (cont'd)

1.2 Elicits, values, and leverages funds-of-knowledge
1.2.1 Teacher provides opportunities for students to share cultural or community developed knowledge in the classroom.
1.2.2 Teacher encourages students to share their funds-of-knowledge and lived experiences.
1.2.3 Teacher leverages funds-of-knowledge contributed in discussion to promote science learning.
1.3 Encourages use and sharing of student language
1.3.1 Students are using language they are comfortable with to explore phenomena.
1.3.2 Teacher uses language offered by students in discussion until the classroom community agrees upon new language.
1.3.3 Students link science words to prior conversations about phenomena in their own words.
1.4 Values students' lived experiences as evidence
1.4.1 Students bring experiences from outside school into class discussion as evidence for explaining phenomena and argumentation.
1.4.2 Teacher values lived experiences in addition to classroom experiences as evidence for explaining phenomena
1.5 Promotes use of students' critical lens to solve problems.
1.5.1 Teacher provides opportunities to develop a critical lens by encouraging students to evaluate and critique their work and ideas.
1.5.2 Teacher provides opportunities to use this critical lens to explore and solve problems in the classroom and in the community.

Clarifying the Framework for Inclusive Three-dimensional Science Classrooms

To answer the question “What does 3D science teaching supporting inclusive classrooms look like?” The *Framework for Inclusive Three-dimensional Science Classrooms*, (Table 2.1), was used to code examples of each element in instruction. Examples of classroom teaching, excerpts from interviews, and field notes were used to substantiate and clarify the final Framework. I discuss specific information about Framework clarification in the next few sections.

Curriculum

Study participants enacted a physical science curriculum called Interactions in their high school classrooms for the duration of data collection. The Interactions curriculum (Damelin & Krajcik, 2015; https://learn.concord.org/interactions) was developed as a 3D science curriculum integrating SEPs, CCs, and DCIs as outlined by the National Research Council in the NGSS (NRC, 2012) to support learners in making sense of phenomena. Interactions includes four units with several investigations in each unit. A driving question begins each investigation, students observe scientific phenomena, and students participate in experiments, readings, activities and simulations to answer this question. Through activities within each investigation, students collect ideas and discover new features and ideas about the observable phenomenon. When students generate new ideas, they add to the driving question board; a visible ongoing collection of student ideas and questions relate to the phenomenon. Over the course of each investigation, students add to, revise, and provide depth to their ideas until students develop an evidence-based explanation for the driving question. Each driving question builds toward developing understanding of the big idea for the unit, and directs unit activities and assessments (Damelin & Krajcik, 2015).

Participants and Context

As a participant observer – a researcher who is also an active part of the context – I approach this work as a Métis (Aboriginal/White) Female from Canada who moved to the U.S. for schooling. I struggled in school, and it was not until high school that I started to experience academic success. Once I learned what knowledge was valued and how to communicate, I began performing well in my classes, graduated high school and went on to university. My first job was teaching in an urban school with a predominately African American population, and while I recognized that I was culturally different from my students, I didn’t have the experiences and training to address issues that arose and struggled to develop a classroom community. Over the years, I realized that developing an inclusive learning environment meant altering my classroom culture one interaction at a time. I firmly believe students, their knowledge, and their ideas are the most important resources in the classroom, and the classroom is most productive when teachers learn to value and elicit that knowledge and those ideas. Administrative, financial, political, and social constraints made it difficult for me to practice in ways I felt promoted equity, and I enter educational research hoping to empower teachers to recognize the rich resources students bring to class and use them to drive instruction.

The first participant, Catherine[3], is a white[4] female veteran science teacher and has worked in a large Midwestern urban school district for the majority of her career. Catherine holds bachelor degrees in psychology and science teaching (all science subjects), and a master's degree in secondary instruction. Catherine taught science in her district for 25 years, and at Smith High School for 15 years. Smith High School is one of three high schools in a large, urban, Midwestern school district and is classified as a Title One school. Students who attended

[3] Participants self-selected a pseudonym.
[4] Participants self-selected their race.

Smith were 71% African American, 17% Hispanic, 11% White, and 1% other (NCES, 2014). District teachers took an 11% pay cut during the study, and lost their instructional planning time contributing to less collaboration between teachers, less time to plan quality lessons, and less time to get to know students and families. During this study, Catherine taught seven, 53-minute classes: 10th grade physical science, 11th grade chemistry, and an elective psychology course for multiple grades. Her classes ranged in size from 20 to over 40 students per class, and she described her student population as "transient" as they frequently moved between the district's four public high schools. She implemented Interactions for the second time in her 10th grade physical science, and 11th grade chemistry courses (Catherine, personal communication, November 5, 2014).

José is a white male teacher at an alternative urban high school in Central Los Angeles serving a predominately Native American student population in a low-income area. He graduated with a bachelor degree in liberal arts, and a master degree in entomology. José taught in an alternative setting and had 35 years of experience teaching in the district. In his unique setting, José saw the same students every day, taught them all their subjects, and because of this had certifications in math, physical education, English, physical sciences and life sciences. The classroom "site" was located in an office building next to a café, a kidney dialysis center, and a Native American legal affairs office. José implemented interactions in the chemistry portion of his class for the first time, and could extend or cut short his lessons since he saw his students every day. Since José had biology and chemistry students, his eight chemistry students would come to the front of the room to engage with José and the curriculum while the remaining seven students worked on other assignments with volunteer tutors. While science wasn't offered each day, sometimes José conducted science lessons lasting a few hours in length. He gauged student interest, and decided whether to move ahead or take a break based on his analysis. José's main focus was building relationships between the students because the isolation of the alternative school from other classes and schools minimized students' opportunities to develop substantial relationships with others. José also talked about his own frustration with his isolated school context in that he missed collaboration with other teachers (José, personal communication October 10, 2015).

Data Generation and Interpretation

Since the goal of examining data is to clarify and provide examples of each element of the Framework, this paper focuses on analyzing video-recorded lessons, audio-recorded interviews, and field notes collected during observations. I selected Catherine and José for observation because they were both skilled, veteran high school science teachers with over 20 years of experience working with urban youth – and I was interested to see how Catherine and José brought expertise of their school context and students to the 3D instruction presented in Interactions. Catherine and José implemented Interactions over several months during which I visited their classrooms once per week to video-record their science classes and audio-record a debriefing interview after the school day. In the interview, I reflected with each teacher on the lesson, how students made sense of the material, and the successes and struggles of implementing the curriculum. If I noticed particular instructional moves that appeared to help student understanding, then I specifically asked the teacher to reflect on the move during the interview. As a participant observer, I interacted with the students to answer questions, help navigate the technology, and acted as an "extra hand" during the lesson. However, I never interfered with Catherine or José's instruction and never discussed instruction with them in any way during teaching. Rather, the respective teacher and I reflected on instruction after the lesson and each teacher decided whether to make instructional changes. Four complete, uninterrupted lessons were selected from Catherine and José for analysis. This resulted in four video-recorded lessons and four debriefing interviews spanning about one month of instruction.

For data interpretation, I used the *Framework for Inclusive Three-dimensional Science Classrooms* (see Table 2.1) to code four classroom observations for each teacher. During coding, I looked for instances reflecting each Framework element in Catherine and José's exchanges with students and used them to provide clarification and examples for each element. After coding each lesson, I reviewed the interviews for evidence of the teacher reflecting the Framework elements coded in the lesson. I also looked for patterns in the ways Catherine and José worked to support students in discussion using the lesson-videos, audio-recorded reflections, and field notes. I then used these data as examples of how each teacher worked to support students in each lesson, and looked across lessons to see if the type of lesson affected the elements used, or if teachers developed different elements over time. I describe patterns of Catherine and José's strategies for supporting students within and across lessons in the next section.

Findings

To show the value of the Framework, this research draws on various data sources to provide additional explanation and support for the *Framework for Inclusive Three-dimensional Science Classrooms*. I tried to capture what experienced teachers may already be doing to bridge 3D instruction with the rich knowledge they have of their students and context to promote inclusive classrooms. My hope is that these examples will serve as a jumping off point for continued research into developing inclusive science classrooms as an important and necessary step for teachers in promoting equitable science classrooms. This section is organized first by defining and clarifying each Framework element, then offering examples and discussion from classroom observations and interviews organized by sub-element. Not all sub-elements are paired with an example from classroom instruction because not all aspects of the Framework were observed in Catherine and José's classroom. One potential contributing factor is that at times students were hard to hear on the video-recorded classroom observations and it was difficult to understand how they were responding to the teacher. In excerpts where I couldn't hear how students responded I relied on my field notes to offer a description of what students were doing or talking about.

1.1 Positions Students as Knowledge Generators

This element shifts the focus away from the teacher as knowledge disseminator, allowing students to generate knowledge in the form of ideas shaped by evidence – observations from inside or outside the classroom, or data analysis from experiments. This validates students as important actors in classroom culture, and shows students that learning cannot take place without open discussion of ideas.

Clarification. During classroom discussion, the teacher does not evaluate ideas as correct or incorrect, but encourages students to provide evidence for ideas. Students evaluate each other's ideas using evidence and develop explanations through discussion.

1.1.1 Students generate ideas and evaluate ideas using evidence.

Catherine 11.05.2014. Students generate ideas during this lesson while exploring "Why do some clothes stick together when they come out of the dryer?" Students brainstormed ideas of things that stick together and things that don't. Early in the lesson, I noticed Catherine using what she called "Socratic questioning" techniques to elicit ideas from students. When students asked her questions, she either responded with another question, or deferred to another student as a source of knowledge. Catherine continually asked questions throughout the lesson “Magnets, that is an interesting one. What do you think makes magnets stick together? How do you know? Kierra, what did you think about Deanna’s question?” (Observation notes, 11.5.2014). She later explained that this style of questioning draws knowledge out of students and into discussion. When students asked her direct questions she responded “I don’t know, lets find out!” Catherine discusses her use of Socratic questioning later in an interview “They get mad at me because I won’t give them the answer, but it isn’t my job. They know the answer and I am going to draw it out of them” (Interview 11.05.2014). Catherine exhibits an asset perspective of her students in that she believes that her students have knowledge and it is her job to draw it out of them. This perspective drives her instruction using the Socratic questioning style and positions students as generators of ideas and knowledge. By using Socratic questioning, she is developing a classroom where the students generate ideas, removing herself as the disseminator of knowledge and placing herself as a learner alongside her students. In Catherine’s classroom, there are no wrong answers – only learning experiences.

1.1.2 Students (as a community) develop explanations by analyzing data and making decisions about whether data collected supports the phenomenon.

José 11.09.2015: José reflected early in the semester on how difficult it was for him to build a community in his classroom due to his isolated teaching context, and his students lack of experience collaborating in his class. “Our students aren’t used to working with each other. Before this [Interactions], they all worked on their own stuff and some never met. As they work together more and more, I can see them coming out of their shell, but it will take time” (Interview, 11.09.2015). However, after a month of working with students, José developed a classroom where students contribute ideas and expanded on those ideas as a community to build understanding. *José 12.11.2015* "We had a few new science words that we learned… electric force and electric field. Can you tell me what the difference was between those?" ***"One is an area and one has to do with strength"***[5] "OK, so one represents an area, thanks Andy. Which one is that, does you remember?" ***"The electric field"*** "Ok, so the field is the area the charge is in. So Andy, based on that - what is force then?" ***"It's something that attracts or repels"*** "Great, does anyone want to add to our definitions?" (Observation,12.11.2015). Here, José refers back to a discussion from the previous day where the terms force and field came up in discussion and asks the class to define them. He then prompts the class to add onto those explanations of the terms giving students an opportunity to develop community-based definitions in their own words.

1.1.3 Teacher consistently validates student's contributions, attributing ideas and knowledge to students, and using their ideas in discussion.

José 11.9.2015, 11.15.2015, 12.4.2015, 12.11.2015 In all of José's recorded sessions, he consistently attributed ideas generated in class back to students. When José encouraged his students to share ideas in class, he also remembered what each student contributed to the discussion and referred to them by name each time that same idea came up. Often, he called on the same student to share their earlier idea: "Anna, could you share the idea you brought up yesterday about the Van de Graff generator?" "Charlie, what did you say to Anna yesterday about fields?" (Field notes, 11.15.2015). By providing such attribution, he is valuing the knowledge they bring to discussion and encouraging other students to

[5] Student responses are bolded and italicized for clarity between speakers.

value those ideas too. He positions students as individual knowledge generators, and likely encourages other students to share their ideas in the same way.

1.2 Elicits, Values and Leverages Funds-of-Knowledge

This element draws on funds-of-knowledge, a term which refers to bodies of knowledge developed historically that are culturally essential for life and well-being (Moll, Amanti, Neff, Gonzalez, 1992). Teachers encourage students to bring funds-of-knowledge into science discussions. While this element can be important for student engagement, encouraging students to contribute funds-of-knowledge in class helps students affirm student's cultural identity and develop appreciation for alternative ways of knowing.

Clarification. Funds-of-knowledge do not have to be from one specific place, but can be from pop culture, peer culture, family culture, or community culture. The intent of using funds-of-knowledge goes beyond promoting engagement or discussion to include valuing and legitimizing who students are and what they already know as important for developing classroom knowledge.

1.2.1 Teacher provides opportunities for students to share cultural or community developed knowledge in the classroom.

Catherine 11.05.2015 In this lesson, Catherine provides opportunities for students to share knowledge by positioning them as scientists with valuable knowledge to contribute. "As scientists, guys, we know that some things stick together and other things don't – we see it in nature all the time. Why? we don't know… it's a phenomenon and what do scientists do? Scientists study phenomenon! (Observation, 11.05.2014)" Catherine understands that her students may not see themselves in science and intentionally works to set up an environment where students are comfortable. She elaborates on this in an interview where she talks about how sometimes students don't speak-up in science because they are afraid to be wrong. “I tell them science is basically learning from mistakes, that is sort of what science is. There isn't a wrong... it is that we didn't support our hypothesis this time. We aren't even wrong; we just learned that this isn't the answer. (Interview, 11.05.2014)” While this example doesn’t specifically target the sharing of cultural or community developed knowledge, developing a safe classroom where students aren’t afraid to be wrong is important for later developing an environment where this type of knowledge is shared and valued.

1.2.2 Teacher encourages students to share their funds-of-knowledge

Catherine 11.11.2014 Catherine encourages students to share what they already know about particular terms such as “components” and “relationships” when students struggled to make sense of a reading called “Aspects of Scientific Models” (Field notes, 11.11.2014). Catherine tried to prompt student understanding of what relationships meant by having them reflect on the relationships in their own lives. “What does the term relationship mean? Describe some relationships you have with friends, parents, your teachers… now what are common between those?” The student responses are inaudible in this section. Catherine tried to get students to think about their understanding of relationships and bring that understanding into class to help them make sense of the relationships in the reading.

1.2.3 Teacher leverages funds-of-knowledge contributed in discussion to promote science learning.

I did not observe teachers leveraging funds-of-knowledge during my observations. This is a complex practice that requires teachers to first develop a safe classroom where student’s ideas are valued and used in discussion. Teachers also make it known that all forms of knowledge and ways of expressing ideas are allowed in class. Once comfortable, it still may take students time before they are willing to share their funds-of-knowledge in class and then teachers must also know how to leverage that knowledge and bring it into discussion. During fall semester Catherine set the stage for students to offer funds-of-knowledge but I didn't see students volunteer it during my visits. This could have been because I was an outsider entering the class and video-recording the lesson, or perhaps students did not yet feel comfortable sharing funds-of-knowledge.

1.3 Encourages Use and Sharing of Student Language

Encourages use of student language and sharing of terminology to make sense of phenomena. If none of the students offer the appropriate science terminology, the teacher can introduce it to students once conceptual understanding is mastered so students have an understanding to "pin" the science word on.

Clarification. This can refer to peer language (slang), non-scientific language, or another cultural language like Spanish. This element allows and encourages students to use and share terms familiar to them to explore content.

1.3.1 Students are using language they are comfortable with to explore phenomena. & 1.3.2 Teacher uses language offered by students in discussion until the classroom community agrees upon new language.

Catherine 11.11.2014 Catherine allowed students to describe the phenomena in their own words while exploring the phenomenon "Why do some clothes stick together when they come out of the dryer?" rather than imposing scientific language on students that they may not yet have mastered. Students struggled with the activity and multiple groups collected conflicting data. "What happened with the T and T tape? They didn't stick?

What is another way we can describe that?" A student replied ***"They moved away"*** "Ok, What happened with the B and the B [Tape]?" [inaudible] "Nothing at all – Did everyone get the same result?" [inaudible] "Ok… so we have one person that said nothing happened and another that said they moved away… anyone else? It looks like we need to retest it then."

After the experiment, Catherine facilitated a discussion about their observations. "Ok, now that we have collected all of our data and organized it into this chart, we need to make sense of it. Can you see a pattern here between the combinations in the results?" Students offer various answers to Catherine's question, and she prompts them to pull the ideas together. "If you had to put all that into one sentence, what would you say? … Opposites attract, and the sames move apart. Does our data support that? … Alright, we will go with that! (Observation, 11.11.2014)." Catherine and the other students continue using "sames move apart" until another student replaces "moves apart" with "repel". Catherine and the students then move to using "opposites attract, and sames repel". Throughout this lesson, Catherine isn't supplying students with new language to talk about their observations, but instead using the same words that the students are using so that the focus is on the ideas and not on the words. Early in the lesson, Catherine adopted the student's observation "moved away". Rather than correcting the student and replacing "moved away" with "repel", Catherine allowed students to describe the phenomena in their own words.

1.3.3 Students link science words to prior conversations about phenomena in their own words.

Catherine 11.11.2014 Catherine scaffolded student understanding of the complex term “components” by connecting it to things they may have heard of or learned before. In this class, students struggled to make sense of a course reading “Aspects of Scientific Models” because they didn’t understand the terms components and relationships, which was central to understanding the text (Field notes 11.11.2014). One student tried to look up components in the dictionary and read the definition aloud to the class, but it didn’t help. Catherine posed the question “what if I had components of a radio, what would I be talking about?” A few students responded in unison ***“The parts!”*** and Catherine responded with “O.k., then what are the parts of a model?” (Observation, 11.11.2014). While this example doesn’t show students linking vocabulary to prior class conversations about phenomena, it does show Catherine scaffolding student understanding of the complex term “components” by connecting the word to things they may have heard of or learned before.

1.4 Values Students’ Lived Experiences as Evidence

This element encourages students to offer in and out of classroom observations/experiences as evidence for phenomena investigated in class. This can refer to students explaining a topic from their unique perspective, or describing phenomena observed outside of the classroom.

Clarification. Students should provide reasoning for bringing experiential evidence into the classroom. Sometimes students may bring experiences that are tangentially connected to the phenomenon. The classroom community evaluates and determines whether the experience is appropriate to use as evidence, and whether it connects to the phenomenon.

1.4.1 Students bring experiences from outside school into class discussion as evidence for explaining phenomena and argumentation.

During my observations, I didn't see examples of students bringing their own experiences into class discussion. This again could be due to my presence as an outsider videotaping the class, or that students were not yet comfortable sharing in class. It could also be that students didn't yet see connections between their lived experiences outside of class and the discussion taking place in the classroom.

1.4.2 Teacher values lived experiences in addition to classroom experiences as evidence for explaining phenomena

Catherine 12.11.2014 During this lesson, students were reading an article about static charge and Catherine took some time out of class to provide them with a connection to something they may have experienced at home. Catherine asked the class "Have you ever tried to put plastic wrap over a bowl at home? Tell me how you use it." Students described using plastic wrap to cover a bowl and it sticking to the bowl. Catherine then asked "does it only stick to the bowl?" and the students brought up that the plastic wrap can curl around and stick to itself, and when the wrap gets stuck on itself, it's really hard to unstick (Observation 12.11.2014). While this isn't a direct observation of students bringing their lived experiences into class, by relating the reading to something students may have experienced at home Catherine is showing students that she values outside of school experiences and observations in class. This sets up a classroom environment where students can bring in their experiences and have them be a valued contribution to the classroom knowledge.

1.5 Promotes Use of Students' Critical Lens to Solve Problems

Students need experiences critiquing each other's ideas using evidence, and using a critical lens to solve problems. Developing students' critical lens and their ability to analyze ideas is an important aspect of working toward this Framework element.

Clarification. Students first need to develop their critical lens by critiquing and evaluating each-others work using evidence gathered from class, or from lived experiences. Students can then apply this process to solve problems.

1.5.1 Teacher provides opportunities to develop a critical lens by encouraging students to evaluate and critique their work and ideas.

Catherine 12.4.2014: In this lesson, the teacher pushes students to clarify their thinking with regard to the design of an experiment that tests how to control the amount of charge applied to an object. Prior to this discussion, students did not have any information about the amount of charge on an object, only that objects could be positively or negatively charged. One student "Deanna" hadn't participated at all in the class discussion, but she proposes an experimental design at the end of class. Catherine pushes her to be more specific in her design.

Catherine: The materials we used to charge things with: fur and silk., so far those are the only materials that we have. We know we can charge and object by rubbing it with fur, we have done that before, how could we control the amount of charge?

Deanna: How much you rub it.

Catherine: So tomorrow then, how do we want to do the experiment? How would you start it, what do we need?

Student 1: We need a procedure

Catherine: Yes! We need a procedure, what should our procedure be?

Deanna: We gotta rub the thang down. You gotta rub it like…. [trails off]

Catherine: Are you going to charge the rod or the balloon?

Deanna: The balloon first

Catherine: How are you going to charge the balloon?

Deanna: by rubbing it down… like 3 times.

Catherine: Ok, and then what?

Deanna: Then you won't let it touch nothing. And then you rub the rod down… or one of the rods down, like 3 times.

Catherine: Three is the lucky number

Deanna: and then you a going to see if the rod will attract the balloon or repel it.

Catherine: How are you going to do that?

Deanna: You are going to put the rod up to the balloon.

Catherine: How up to? We have to be specific remember?

Deanna: Yeah

Catherine: Right, be specific, where are you going to put the rod?

Student 1: Like 1cm away!

Deanna: I didn't ask you!! Like the balloon is right here (gestures) and you are going to go closer and closer and then you will see if it attracts or repels.

Unfortunately, the bell rang before the discussion could continue, but here we see Deanna proposing a fairly sophisticated experimental setup using evidence from previous class experiments. Deanna analyzed the problem "how does the amount of charge affect what we see?" and used evidence from previous investigations to propose and experiment and find out.

José 11.20.2015 In this lesson, I observed students struggling with an investigation and ask José to help them problem solve. Instead, José referred the question to a student at another table who was able to critique their experimental set-up and offer suggestions. The students were hanging different objects from a string from the table and testing to see how they would be affected by a charged rod. Students could try out any object they wanted, but had to record the data. The table on the left side decided to test a pair of scissors but when they tested with the rod, nothing happened. Kayla pointed out that the scissors were metal, so they should see something, and asked José for help. José walked over to Vincent and asked him to take a look at their experimental set-up and offer suggestions. Vincent walked over to their table and noticed that the scissors were too heavy to be affected by the charged rod. He untied the scissors from the string and handed Kayla a paper clip. Kayla tied the paper clip to the string and they tried the experiment again. I could hear the students exclaim ***"ooooh!"*** and saw smiles on their faces as they recorded the findings. (Field Notes, 11.20.2015). Here we see José giving other students opportunities to critique each other's work, just as Vincent critiqued Kayla's experimental design, and the students were figure out why the metal scissors weren't affected by the rod.

1.5.2 Teacher provides opportunities to use this critical lens to explore and solve problems in the classroom and in the community.

I didn't see evidence of either teacher providing opportunities to use a critical lens to explore problems in the classroom or community. It may have been too early in the curriculum for teachers to engage in this with students, and perhaps they focused more on developing that critical lens. One drawback to examining use of a provided curriculum is that teachers were not developing their own lessons. Perhaps it was difficult for teachers to see how issues in the community could be brought into class, or they didn't think to do so because of their participation with the curriculum.

Discussion

In this research paper, I developed, validated, and clarified a Framework that describes 3D science teaching practices that promote inclusive classroom environments. I anchored the Framework in the literature on multicultural education and equitable teaching in science classrooms to bridge to position this Framework not as a collection of strategies, but as a pedagogical shift in science instruction. As states move to adopt ideas presented in the NGSS, teachers will have to integrate 3D instruction into their teaching. *The Framework for Inclusive Three-dimensional Science Classrooms* integrates research-based inclusive science teaching pedagogies with 3D instructional strategies to provide teachers, researchers, and teacher educators with a guide to facilitate this transformation.

Catherine and José had very different student populations teaching in different areas of the country, but we have evidence supporting that they implemented 3D teaching practices that also facilitated the development of inclusive learning environments for their students. This is important because we know that teachers can integrate knowledge of their students and context in ways that best engage their students in 3D learning. While Catherine and José did not have specific training in the practices described in the Framework, they brought their experience as veteran teachers in urban schools, and their asset perspectives of student learning to their instruction. What resulted were classroom examples of some Framework elements to further clarify its aims for teachers, researchers and teacher educators for making similar changes at all levels of teacher preparation and practice.

The Framework for Inclusive 3D Science Classrooms as an Observational Tool

I used *The Framework for Inclusive Three-dimensional Science Classrooms* to determine whether I could capture what veteran urban science teachers were already doing in their classrooms to integrate their knowledge of content with knowledge of their school context. In doing so, I ran into a few issues and also identified some nuances in the Framework. There are five elements in the Framework with sub-elements that describe what teachers and students are doing to promote each element. One of the first issues that I had was that as an outside observer, it was often hard to hear what students were saying or view what they were doing. For example, I might see that students are engaged in small group conversation, but not hear what the students are conversing about. Similarly, I could often see what students were doing (carrying out an experiment) but not hear the conversations around that practice. What I ended up including in the results section weren't necessarily descriptions of what students were doing but how the teacher may be fostering that student practice. In this way, the Framework as is may serve better as a reflection tool for teachers than an observational tool for researchers. Perhaps some tweaks to wording, or multiple versions of the Framework would best serve the needs of more stakeholders.

Another feature I learned using the Framework as an observational tool is that I started to see different grain sizes in the elements, and nuances in the sub-elements. For example, *Positions students as knowledge generators* is a fairly large-level element, and the four other elements likely contribute to positioning students as the center of knowledge. Similarly, lived experiences are one facet of funds-of-knowledge and while element four points to lived experiences as being used for evidence, these two elements are also connected. As for nuances within the elements, I noticed that both Catherine and José engaged in practices that supported classroom environments that would facilitate sub-elements, but didn't necessarily get at the core of what the element described. For example, in *1.4.2 Teacher values lived experiences in addition to classroom experiences as evidence for explaining phenomena* I didn't necessarily see students offering lived experiences and the teacher valuing those, but instead it was Catherine who brought in an experience from outside of class into discussion. This action showed students that she valued these out of school experiences which may later lead to the teacher valuing those experiences that students bring into discussion.

Implications for Moving Inclusive Science Instruction Forward

The Framework for Inclusive Three-dimensional Science Classrooms has promise for several important kinds of work moving forward. The NRC calls for an integration of equitable practices in NGSS-aligned classrooms, and educators will need tools to support this type of instruction (NRC, 2012). *The Framework for Inclusive Three-dimensional Science Classrooms* acts as a tool for re-conceptualizing how science classrooms are structured. The Framework also challenges deficit perspectives by drawing on funds-of-knowledge as a conceptual tool in defining inclusive 3D instruction as presented in the Framework (Calabrese Barton et al., 2014; Moll et al., 1992). My hope is that teachers, researchers, and teacher educators can use the Framework to promote and reframe what inclusive 3D instruction looks like in practice. Researchers can use the Framework as a guide to analyze teaching and learning in science classrooms, or to examine how teachers make use of this tool to improve their classroom environments. Second, teachers can use the Framework to reflect on their teaching and to facilitate 3D instructional practices that support the development of inclusive learning environments to work toward equitable science classrooms. Third, instructional coaches working with teachers to implement NGSS-aligned lessons can also use the Framework as a guide for analyzing instruction or promoting discussion with teachers. Finally, the Framework can assist teacher educators in supporting the development of candidates' inclusive science teaching by providing grounding for work done in teacher preparation courses and in the field.

While shifting from traditional teaching practices to 3D teaching will be challenging and will require extensive support (NRC, 2015), my hope is that science teachers, instructional coaches, researchers and teacher educators can use this Framework as a guide to accelerate implementation of inclusive 3D instruction and further promote equitable opportunities in science for all students. By so doing, science classrooms will become places of learning in which all students develop the knowledge and intellectual capacity to explain phenomena and solve problems.

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CHAPTER 3: STUDY TWO

Science Teacher Learning of Inclusive Three-dimensional Instruction Through Participation in a Sustained Professional Learning Program

Abstract

Integrating inclusive science instruction in three-dimensional classrooms is an important step to promoting equity in science. Supporting teachers in transforming their teaching to three-dimensional instruction while meeting all students' learning needs will require sustained support, and time to adapt. In this study, I explore the aspects of a Professional Learning Program (PLP) teachers engage with and how they enact their learning in the classroom. First, I developed a research-based, year long PLP focused on integrating inclusive teaching practices with three-dimensional instruction. Five teachers from the Los Angeles Unified School District participated in the program while implementing a three-dimensional physical science curriculum in their classrooms, and I selected three teachers for case study analysis. Data collection included classroom observations, recordings of professional learning sessions, teacher interviews, and field notes. Findings indicate that each teacher engaged with different aspects of the PLP to make changes in instruction that supported students and met the individual needs of their context.

Introduction

The National Research Council (NRC) and the Next Generation Science Standards (NGSS) describe a vision for science education focused on three-dimensional (3D) learning, while reiterating the importance of science for all students (NGSS Lead States, 2013; NRC, 2012). Three-dimensional learning refers to instruction that braids together disciplinary core ideas, crosscutting concepts, and scientific and engineering practices to support student understanding of natural phenomena. Ensuring science for all students involves delivering equitable opportunities to students; where each student is provided what they need to be successful (Kolonich, Richmond, & Krajcik, 2017). One approach to promoting equitable opportunities to learn science in 3D classrooms is implementing 3D instruction with inclusive pedagogies. Inclusive science teaching is grounded in sociocultural learning theory and promotes classrooms where social and cultural interactions between students and teachers are necessary for learning. In inclusive 3D classrooms, students feel safe sharing ideas and evaluating the ideas of others based on evidence, to explore natural phenomena (Kolonich, Richmond & Krajcik, 2017). Integrating inclusive teaching practices in 3D science classrooms may present challenges for educators since it requires a shift away from more traditional forms of instruction that are still prevalent in today's science classrooms (Reiser, 2013) where the teacher holds knowledge and transmits that knowledge to students (Mirra & Rogers, 2016). Considerations for teacher professional learning with respect to inclusive 3D instruction will be important as many teachers have not experienced it for themselves and the transition will likely take both time and targeted support (NRC, 2015; Wilson, Schweingruber, & Nielsen, 2015).

Researchers have argued that disparities in student test scores in science across the demographic spectrum result from inequalities in student opportunities to learn science in school

(Milner, 2010; Quinn, 2015). Just as students require equal opportunities to learn science, providing all teachers opportunities to learn research-based practices for supporting science learning is important in transforming science classrooms. Research shows that teachers – just like students – respond differently to the same instruction (Desimone & Garet, 2015). For example, teachers may be focused on contextual problems impacting their classrooms, such as a how best to provide instruction to English Language Learners, and these contextual factors may in turn impact what teachers are willing and able to get from professional learning activities (Desimone & Garet, 2015; Roschelle et. al. 2010). Providing teachers with access to multiple types of professional learning activities provides more opportunities to meet the learning needs of individual teachers. Districts in the United States have generally been moving away from the one-time workshops that have been the predominant learning opportunities for teachers. Instead, professional learning providers are increasingly basing their programs on research promoting content-focused, sustained support and working to ensure all teachers have access to learning that is content focused, longer term, and meets multiple learning needs (Desimone & Garet, 2015 Wei, Darling-Hammond & Adamson, 2010). Kelly defines teacher learning as the process of moving toward "expertise", acknowledging Lave and Wenger's (1991) notion of expertise as full participation in social settings (Kelly, 2006). Kelly suggests that teacher learning includes engagement in "reflective, discursive, collaborative and inclusive practices to improve their work with colleagues and students" (Kelly, 2006 p. 512).

Based on this research on teacher learning and effective professional learning, I developed a year long program for teachers focused on providing opportunities for collaboration, sustained support, and multiple entry points for diverse teacher learners. The specific learning focus for teachers was on supporting inclusive, 3D instruction where all students feel safe to share and evaluate ideas. I also worked to establish an inclusive, safe environment for teacher learning to both model inclusive instruction for teachers, and to encourage their collaboration and participation in the group. Five secondary science teachers from the Los Angeles Unified School District (LAUSD) participated in this Professional Learning Program (PLP) during the 2015-2016 school year while implementing a 3D physical science curriculum in their classrooms. In this paper, I examine what aspects of the PLP different teachers interacted with and how they put their learning into practice in the classroom. Artifacts, audio/video recordings from classroom observations, PLP sessions, teacher interviews, and field notes were analyzed to determine whether teachers were successful in shifting instruction toward PLP goals. I hope to provide insight about the aspects of teacher professional learning that best supports teachers in developing inclusive 3D classrooms to give all students equal opportunities to be successful in science.

Conceptual Framework

The development of a PLP for teachers was grounded in three areas of literature described in this section. First, I review research on effective PLPs, and describe how that research was leveraged for my particular focus on inclusive 3D instruction. Next, because development of an effective professional learning community was an important aspect of the overall PLP, I also explore specific features of effective professional learning communities. Finally, I describe inclusive, 3D instruction as the learning focus for teachers participating in the PLP.

Professional Learning Programs for Teachers

Science teacher professional learning refers to acquiring new ideas, revising existing ideas, and, integrating new knowledge with practice (Davis, 2003) and takes place in social settings where teachers can engage in collaboration (Kelly, 2006). Professional learning programs support teacher learning to effect positive change in student's academic success (Whitworth & Chiu, 2015). Researchers have highlighted factors that can influence teacher change in positive or negative ways including: school context, years of experience, motivations for attending, school culture, leadership support and working conditions, and access to resources (Whitworth and Chiu, 2015). In particular, PLPs with strong links between teaching content and personal learning are positively associated with changes in teacher practice (Davis, 2003), and making room for this important link was a focus of my PLP. As other researchers before me have done, I take an asset perspective to teacher learning in that I assume teaching to be a complex profession and teachers to be professionals. I aim to draw on teachers' own expertise and knowledge of context to improve practice (Carter-Andrews, Bartell, & Richmond, 2016).

A current literature review on science teacher PLPs revealed five important features that effective science teacher PLPs share. Desimone and Garet (2015) identify (and other researchers have taken up) five essential features of effective professional development including: 1) a focus on content knowledge, 2) engaging teachers in active learning, 3) a coherent program, 4) sustained duration, and 5) collective participation (Desimone & Garet, 2015; Luft & Hewson, 2014; Wilson, Schweingruber, & Nielsen, 2015). Researchers recommend that the five features inform the planning and enactment of science teacher PLPs to maximize effectiveness since different teachers may experience different rates of change.

Drawing from the research on effective teacher PLPs, I re-conceptualize the five essential features of effective professional development to fit my specific focus on inclusive 3D instruction. The re-conceptualized features include 1) a focus on three-dimensional instruction, 2) engaging teachers in examining instructional evidence, 3) coherence within and across activities, 4) sustained duration, and 5) participation in a professional learning community (see Table 3.1). I re-conceptualize content focus as a focus on three-dimensional instruction because the nature of science content knowledge has changed. Wilson, Schweingruber, and Nielsen (2015) argue that one area where science teachers must develop expertise is "content knowledge, including the understanding of disciplinary core ideas, crosscutting concepts, and scientific and engineering practices" (p. 109). To focus on active learning, I focus the Interactions PLP specifically on engaging teachers in examining instructional evidence, such as analyzing student work (Whitworth & Chiu, 2015), or reflecting on their own practice – activities that support instructional change (Stewart, 2014; Wilson, Schweingruber, & Nielsen, 2015).

The last three features are similar to the essential features described by Desimone and Garet (2015). Coherence within and across activities refers to how well the professional learning activities relate to one another, and to the learning goals that teachers identified during planning. Coherent programs also include activities that teachers can implement in their own classrooms (Whitworth & Chiu, 2015). Teachers participating in coherent PLPs are more likely to improve their instruction (Garet, Porter, Desimone, Birman, & Yoon, 2001). Luft and Hewson (2014) concluded that more time spent in professional learning activities is required for more difficult changes in practice. Our sustained, professional learning program included more than 50 hours of articulated support for teachers. Finally, we conceptualize collective participation as having teachers participate in an ongoing professional learning community. The Interactions professional learning community was an important aspect of the PLP, and since effective professional learning communities have their own rich base of research, they are discussed in greater detail in the next section.

Table 3.1: Essential Features of a PLP focused on Inclusive 3D Instruction

Essential Feature	**Description**
Focus on 3D Instruction	Activities are focused on 3D instruction, including integrating the three dimensions in instruction and how students learn in three dimensions.
Examining Instructional Evidence	Teachers are given opportunities to gather evidence they will use to change instruction by examine their instruction, discussing research-based strategies with other teachers, and analyzing student work.
Coherence Within and Across Activities	All professional learning activities align with the program goals, and build upon one another. This may include altering planned activities to focus on more pressing issues that come up during the course of the program.
Sustained Duration	PD activities continue throughout the school year, build on one another, and include at least 50 hours of contact time.
Participation in a Professional Learning Community	As part of the professional learning program, teachers engage in a weekly, facilitated professional learning community with other teachers in the same district teaching the same material.

Research on teacher learning also points to the importance of instructional coaching as part of a PLP. “Instructional coaching is characterized by non-supervisory, non-evaluative, individualized guidance and support that takes place directly within the instructional setting” (Taylor, 2008). Some researchers have termed this “embedded professional development”, emphasizing that it is situated in the context of practice (Gallucci, Van Lare, Yoon, & Boatright, 2010; Wilson, Schweingruber, & Nielsen, 2015). The aim of instructional coaching is to provide targeted support for teachers to improve instruction, examine their instructional practice, and connect them to professional networks that enhance social capital (Taylor, 2008). Research also suggests that important considerations during PLP development and implementation include understanding that teachers have individual learning needs (Roschelle et. al. 2010), and that teacher learning can be influenced by local policies, curriculum and school culture (Penuel, Gallagher, & Moorthy, 2011).

Teacher Learning in Professional Learning Communities

Providing teachers with opportunities to collaborate with other teachers of similar content and grade level is another important aspect of an effective professional development program (Desimone & Garet, 2015; Kelly, 2006). Professional learning communities are defined as "a group of teachers who meet regularly with a common set of teaching and learning goals, shared responsibilities for work to be undertaken and collaborative development of pedagogical content knowledge as a result of the gatherings" (Richmond & Manokore, 2011 p. 545). Professional learning communities are described as an effective way to encourage collaboration through regular meetings centered on a shared learning goal (Dufour, 2004). Three components of an effective professional learning community include 1) an emphasis on learning, 2) a culture of collaboration, and 3) a focus on results (Dufour, 2004; McConnel, Parker, Eberheart, Koehler, & Lundeberg, 2013). Developing a culture where teachers feel comfortable sharing with their peers is important for teacher growth in and out of the professional learning community. Scholars researching the effectiveness of professional learning communities by evaluating teacher talk concluded that communication within a learning community enhanced teacher knowledge and confidence (Richmond & Manokore, 2011).

Typical professional learning community models include groups of teachers working at the same school or the same district, with teachers meeting after school, on weekends, or during summer break. However, online professional learning communities are a growing phenomenon that allows teachers in different schools and districts to meet online in synchronous discussion groups (Fulton, Doerr, & Britton, 2010). Videoconferencing provides practical learning in a professional setting, while opening access to professional learning for teachers who may otherwise be unable to travel due to distance or time constraints (McConnell et. al, 2012). While effective professional learning communities can include face-to-face and videoconference models, the types of activities teachers engage in are important for focusing teacher attention on student performance. Researchers recommend activities for teachers such as analyzing student work, and exploring effective strategies that facilitate student learning (Stewart, 2014). Providing teachers with opportunities to learn effective instructional strategies and analyze student's thinking promotes targeted improvements in instruction.

The professional learning community is an important part of the overall PLP designed for this study, and consists of teachers from the same district who taught the same course meeting once per week for one hour in a virtual environment. Teachers engaged in two types of activities: presentation and analysis of student work, and discussing book chapters or articles on effective, inclusive three-dimensional instructional strategies.

Inclusive Three-dimensional Science Classrooms

Science for all students as a vision for K-12 science education was first introduced by the American Association for the Advancement of Science, and has been highlighted as an important vision by the NRC and the NGSS (AAAS, 1994; NGSS Lead States, 2013; NRC 2012). Classrooms aligned to the NGSS give students opportunities to explain phenomena, engage in scientific practices, and develop lasting scientific knowledge (Lee et. al, 2015). Providing opportunities for all students to learn science through participation in a legitimate scientific community (Lave & Wenger, 1991) will require safe, inclusive classroom spaces where students from all backgrounds feel safe to and excited to share ideas and critique explanations. This type of inclusive classroom space contributes to student engagement and social construction of knowledge (Mensah, 2013) and can help teachers promote equitable science classrooms.

Developing inclusive 3D classrooms where all students feel safe to share and evaluate ideas requires teachers to attend to the linguistic, cultural, and emotional differences present in the classroom. Kolonich, Richmond, and Krajcik (2017) propose *The Framework for Inclusive Three-dimensional Science Classrooms* to serve as a resource for teachers, teacher educators, and researchers seeking instructional changes that support all students in science learning. The framework details five elements that integrate these important instructional practices, including: 1) positioning students as knowledge generators, 2) eliciting, valuing and leveraging funds-of-knowledge, 3) encouraging use and sharing of student language, 4) valuing students' lived experiences as evidence, and 5) promoting use of students' critical lens to solve problems (Kolonich, Richmond, & Krajcik, 2017). Each of the five elements includes a clarification and sub-elements that depict what both teachers and students are doing to promote each element, as shown in Table 2.1 on page 30.

"Positioning students as knowledge generators" is grounded in funds-of-knowledge as a conceptual tool, and refers to shifting the focus from the teacher as the knowledge holder, to students. In classrooms that position students as knowledge generators, students develop ideas and make decisions about them using evidence in class discussion. Teachers do not evaluate ideas as incorrect or correct, but allows students to evaluate their own ideas based upon evidence and reasoning. "Eliciting, valuing and leveraging funds-of-knowledge also builds from literature on funds-of-knowledge as an important conceptual tool (Calabrese Barton, Tan, & O'Neil 2014). For teachers, this means understanding that students already come to class with rich knowledge resources built over time in their home communities, and that building on those rich knowledge bases is essential to student learning. By eliciting, valuing, and leveraging funds-of-knowledge, teachers not only foster student engagement, but also affirm student identities and promote appreciation in all students for unique thoughts and ideas. "Encouraging use of student language to explore phenomena" compels teachers to honor student identities by allowing them to explore concepts in their own words first, and learn formal science language after they have mastered a concept. This student language includes home language, peer language (slang), or other non-scientific language and can provide an important stepping-stone to sharing ideas and developing deep understanding.

"Valuing students' lived experiences as evidence for explanation and argumentation" challenges teachers not only to leverage lived experiences for class discussion, but to allow students to use informal observations outside of school in their evidence-based explanations or in argumentation. Students can decide among themselves that experiences either fit or don't fit the phenomena as they collect more evidence, but must consider all the evidence and can't just ignore it. Finally, "promoting development and use of a student's critical lens to solve problems" requires teachers to allow students to evaluate work, ideas, and observations using evidence and reasoning – and also to use that developed skill to explore problems in the local community or outside world. Students will first need to develop their critical lens through in-class work, and then apply it to other situations. These five elements informed the development of the professional learning program, and were also used during data analysis to examine instructional changes. Additional information about each of the five elements can be found in Table 2.1 on page 30.

Adopting pedagogies that develop inclusive classroom environments maybe difficult for some teachers. Student-centered instructional methods, like those described in *The Framework* *for Inclusive Three-dimensional Science Classrooms* disrupts the traditional distribution of knowledge and learning opportunities, which may lead to teachers and privileged families feeling threatened or left behind (Davis, 2003). Teachers who experience a lack of support for instructional change from students, parents and administrators may be more resistant to change (Davis, 2003). Other factors such as time, access to resources, school culture, and experience may also impact teacher's ability to implement change (Whitworth and Chiu, 2015). We know that classrooms in urban communities are often underfunded, overcrowded, and lack necessary supplies - further constraining teacher's ability to implement change (Carter-Andrews, Bartell, & Richmond, 2016) and making it even more important to provide sustained, coherent, research-based professional learning opportunities for urban teachers.

Professional Learning Program Development

The Interactions Physical Science Curriculum

The PLP I developed is grounded in the implementation of a 3D science curriculum called Interactions that teachers enacted in their high school classrooms for one school year during participation in the PLP. Interactions was designed to help students develop understanding of electrical interactions at sub-microscopic scales, and is a 3D science curriculum integrating scientific and engineering practices, crosscutting concepts, and disciplinary core ideas as outlined by the National Research Council in the Next Generation Science Standards (NGSS Lead States, 2013; NRC, 2012). The Interactions teacher materials were designed to be educative meaning they were designed to support both teacher learning and student learning. The materials provide detailed instructions to help teachers facilitate meaningful discussions, and develop classroom knowledge based on evidence. Interactions includes four units broken down into several investigations. Each investigation begins with a driving question that students work to answer by participating in experiments, readings, activities, and simulations. In each activity, investigation and unit, students observe real-life phenomena that related to a driving question – a question that describes a problem space that challenges students to explore further (Singer, Marx & Krajcik, 2000; Weizman, Shwartz & Fortus, 2008). Through activities that take place throughout an investigation, students collect ideas and discover new things about the observable phenomenon. Each time students make discoveries or generate ideas, they are added to the driving question board (DQB), creating a visible ongoing collection of student ideas and questions related to the phenomena. Over the course of the investigation, students add to, revise, and provide depth to their ideas until they are able to provide evidence-based explanations for the driving question. Each driving question builds toward the big science idea for the unit, which guides all activities and assessments (Damelin & Krajcik, 2015).

Program Development for Los Angeles Science Teachers

Interactions was a five-year grant funded by the National Science Foundation to develop a NGSS-aligned, 3D physical science curriculum for teachers. Prior to this study, the Interactions team already had teacher professional learning activities in place to support instruction during curriculum implementation. Teacher training started with a summer institute to introduce the curriculum, and included a virtual, bi-weekly professional learning community where teachers would meet to analyze student work, using the *Consultancy Protocol Adapted for Examining Student Work* (NSRF, 2014). This protocol was intended to ensure a safe community for teacher sharing where teachers felt comfortable sharing, critiquing and challenging ideas. The protocol also helped keep the group focused on the student work analysis (see Appendix A). In conducting this study, I Included both the summer training and the student work analysis as part of the professional learning program, designed additional activities that supported inclusive 3D instruction, and incorporated the five re-conceptualized features for effective professional learning programs discussed above.

The Interactions PLP I further developed includes five separate activities designed to build upon one other over the course of the school year. The activities were 1) initial summer institute, 2) analyzing student work during weekly sessions, 3) reviewing research-based instruction during weekly sessions, 4) Saturday professional learning sessions, and 5) individual instructional coaching. A summary of the professional learning activities, agenda, learning goals, and alignment to the core features of inclusive 3D instruction can be found in Table 3.2. The PLP started with the summer institute where I introduced the teachers to the curriculum. It was very important to me that the teachers all got to know each other and became comfortable talking about potentially vulnerable topics, so time was spent during this training to encourage a comfortable and friendly community. One month after school started, we started meeting weekly for one hour after school in a virtual environment to conduct an analysis of student work or to review an article describing equitable teaching practices. It is important to note that the analysis of student work was intended to help teachers understand how their students were making sense of science concepts and not meant to be an evaluation of their teaching.

Since presenting student work to a group of colleagues can put the presenter in a vulnerable place, there was always another teacher assigned as a facilitator to make sure the group stayed on time, on topic, and on tone. On tone refers to avoiding judgments or suggestions, and focusing on helping the presenter think more deeply about how students are making sense of the material. To prepare teachers for the important role as a facilitator, a colleague and I first modeled the presenter and facilitator roles in a professional learning session. During the first teacher-led session, ten minutes were also set aside for the group to reflect on the presenter and facilitator roles. This time was set aside for teachers to discuss how they felt in the roles, what worked and didn't work.

The two Saturday sessions were designed to be a continuation of the professional learning community, but gave us opportunities to explore three-dimensional instruction and inclusive teaching strategies more deeply. The instructional coaching sessions spanned the entire semester and took place after a classroom observation. The instructional coaching sessions were focused on inclusive science pedagogies and making the classroom a safe environment. Different teachers used this time in different ways – some to debrief videos of their own instruction with me, some to ask advice on dealing with a particular student or situation, and others had me look for specific things in their teaching to talk about afterward. In all cases, teachers were examining instructional evidence to make changes in their classrooms.

The Interactions PLP was designed to be iterative, in that activities were often altered or added to scheduled meetings in response to questions or concerns that came up during PLP implementation. For example, teachers reported in October that they were having trouble assessing changes in student models over time and providing helpful feedback. Based on this information, I included an activity in the November Saturday session where teachers had the opportunity to grade student model revisions over time in groups and then discuss the grading process. I relied on my knowledge of research on teacher professional learning in designing changes to sessions that were attentive to teacher's immediate needs. As a group, the teachers and I held a discussion about providing helpful feedback to students that would build on student ideas and support them in improving modeling practices.

Table 3.2: Interactions Professional Learning Program Summary

PLP Activity	Activity Agenda	Teacher Learning Goal	Essential Features of a PLP for Inclusive 3D Instruction
Summer Institute	Model teach and debrief, present 3D instruction	Introduce 3D instruction and establish professional learning community	Focus on 3D instruction, participate in a professional learning community
Professional Learning Community – Student work	Presentation of student work by teachers for analysis	Explore student thinking to inform instructional decisions	Examining instructional evidence, Participation in a professional learning community
Professional Learning Community – article review	Discuss articles and book chapters focused on instructional techniques	Explore research-based equitable teaching strategies in science to inform instructional decisions	Examining instructional evidence, Participation in a professional learning community
Saturday Professional Learning Sessions	Teacher presentations, practice grading models and explanations with rubrics	Dig deeper into research-based 3D instructional practices and how they support student learning	Focus on 3D instruction, Coherence within and Across activities, sustained duration
Instructional Coaching Sessions	Class observation and debrief with professional learning facilitator	Promoting growth mindset for students and teachers and focus on valuing and accessing student knowledge	Examining instructional evidence, Coherence within and across activities, sustained duration

This study began with fifteen teachers who participated in the summer institute held in June prior to the 2015-2016 school year. Due to teacher displacement and course changes, only five teachers remained to continue participating in the program when school started in August. All five teachers remained in the program through the end of the school year, and from this group three were selected for case study analysis based on the amount of data collected for each teacher.

The summer institute took place over three days during summer vacation, and included fifteen teachers from LAUSD. The focus of the summer institute was on three-dimensional learning, specifically engaging students in constructing models to explain phenomena. Professional learning activities included model teaching and debriefing episodes, presentations on NGSS and three-dimensional learning, analysis of student models, and analyzing student work using the *Consultancy Adapted for Examining Student Work* (Appendix A). Participants of the summer institute included the five participating teachers in this study. This initial professional learning activity helped teachers understand what three-dimensional learning can look like in the classroom, provided a general overview of curriculum supports, and introduced them to the weekly professional learning community model.

At the start of the school year, five teachers remained to participate in the virtual professional learning community lasting one hour each week during the year. The weekly meetings consisted of two different activities: 1) An analysis of student work to help inform instructional decisions, and 2) a book study emphasizing the development of inclusive learning environments with diverse student groups. For student work analysis sessions, a teacher brought an example of student work to highlight an issue they were having in the classroom. Teachers took turns in two roles: each teacher presented one session per semester, and facilitated another session using the *Consultancy Adapted for Examining Student Work* to keep the discussion on task. Analysis of student work helped inform instructional decisions and promoted inclusive learning environments. During the book study, teachers read chapters from the book *NGSS for all Students* (Lee et. al, 2015), which grounded group discussion in teaching vignettes depicting equitable instruction. Discussions in the virtual meetings focused on exploring how students made sense of phenomenon, and on exploring strategies to access student's funds-of-knowledge.

Funds-of-knowledge as a conceptual took was an important theme threaded through all of the professional learning activities.

Two Saturday in-person professional learning sessions were offered during fall semester that focused on both three-dimensional learning techniques and on promoting inclusive 3D classrooms. These sessions included structured activities to support teacher learning, including model-teaching and debriefing episodes, analysis of scholarly articles, and a continuation of weekly meetings. The first session in September highlighted using a DQB to elicit and organize student ideas during discussion. The second session in November gave teachers an opportunity to share innovative things they were doing to support student learning, and focused on scaffolding the development and revision of student models based on evidence collected in and outside of class.

Each case study teacher received support in the form of instructional coaching from myself as needed to deconstruct classroom situations, address problems in implementing 3D learning in their context, and tackling classroom management with new styles of teaching. Instructional coaching activities took place after classroom observations, and promoted valuing, acknowledging, and the importance of accessing student ideas in the classroom. Teachers selected how often instructional coaching took place, and the focus of these coaching sessions. Topics varied, but included promoting a growth mindset (all students have the ability to learn and grow) for students and for teachers, and practices that worked to foster student engagement and discussion.

Methods

To explore my research question, I used a multiple case study approach (Yin, 2014) and selected for analysis three out of five secondary science teachers who participated in the

Interactions PLP. Multiple case studies were developed from data collected during teacher implementation of the 3D physical science curriculum "Interactions" in their classrooms. Data sources included curriculum documents, audio-recorded interviews with teachers, video-recorded lesson observations, field notes taken during classroom observations, and video-recorded professional learning activities. This methods section includes a description of all participants in the PLP, including the three case-study teachers, a description of the case-study design organized by teacher, and description of case study analysis.

Participants and Context

Role as a participant observer. I approached this work as a Métis, monolingual female from Canada who moved to the United States for my education. For this study, it is important to note that I am culturally different from the teachers that I work with, and the student population of each school. As a monolingual female, I was not able to understand some of the language being spoken in class, and my data interpretation includes only what I am able to interpret given my identity. My role as a researcher in this study was that of a participant observer – a researcher who is an active part of the research context (Glesne, 2011). During classroom observations, I primarily recorded video and took field notes, but I also interacted with students to answer questions or help with activities. I took great care not to undermine the work of the teacher in the classroom, and only engaged with students if it fit with the community the teacher had developed. In addition, I served as an instructional coach for teachers and participated in all professional learning sessions with them, including the weekly virtual professional learning community. Since I was integrated into the learning community, I cannot completely separate myself from the research context and am conscious of the benefits and drawbacks of engaging as a participant observer throughout the course of the research. At times, I may have made decisions that are good for a professional learning community, but not necessarily good for research purposes. For example, if an issue came up during weekly meetings – such as culturally relevant instruction – I set aside time to discuss the topic in depth rather than waiting to see how teachers made sense of the topic on their own. Since my ultimate aim was to support teachers in developing inclusive three-dimensional learning communities for their students, I acted accordingly.

Autumn and Toby. Autumn[6] and Toby were an important part of the PLP as active participants who supported case study teachers in their learning. Autumn and Toby were not selected for case study analysis due to contextual circumstances that limited data collection in their classrooms; however, we acknowledge their contributions as important participants in this study. Contributions from Autumn and Toby appeared in data analysis, and in the findings section presented in this paper.

Nathan and Mark. Nathan and Mark are described here together to highlight the similarities and differences in their teaching experience and context. Nathan was an experienced, white[7] male physics and engineering teacher well known throughout the district, with more than 20 years of combined teaching and administrative experience. He had a bachelor's degree in biological science, a master's degree in educational administration, and had also started a Ph.D. program focused on assessment in education. The school he taught at in Southern Los Angeles served a predominately Latinx community of low socioeconomic status, and was also a Magnet school with a focus on computer science and engineering. Nathan also served as the after-school robotics coach, a developer for the district's physics assessments, and a union representative. Nathan implemented Interactions in his first, second, and third hour physics classes with each

[6] Participants self-selected their pseudonym.
[7] Participants self-selected their race.

lasting 84 minutes. During professional learning sessions, Nathan was most interested in getting students involved in an interactive DQB to help promote coherence across the activities and units for the students, and to fight against the common perception by students that science is just "where you do something different each day".

Mark was a Korean-American male who taught at a school in Southern Los Angeles serving a predominately Latinx student community of low socioeconomic status. His bachelor degree was in English, with certifications in English and chemistry. Mark taught chemistry at this school for eight years, and his department and school were supportive of him transforming his teaching. Mark served on a number of committees in the school aimed at enhancing literacy, writing, and reading skills in all classes, and Mark worked very hard during implementation to find meaningful ways to work these strategies into Interactions to support student learning. Mark implemented Interactions in five chemistry classes and one honors chemistry class. His school was different in that each class lasted two hours (120 minutes each). During weekly collaborative sessions, Mark was generally quiet (a self-described listener) and deferred to the teachers with more experience.

José. José was a white male teacher at an alternative school in Central Los Angeles serving predominately a Native American student population in a low-income area. He graduated with a bachelor's degree in liberal arts, and a master's degree in entomology. José had thirty-five years of experience teaching in the district and saw the same students all day, every day, teaching them all their subjects. José earned certifications in math, physical education, English, physical sciences, and life sciences to teach at this school. The classroom "site" was located in an office building next to a café, a dialysis center, and a Native American legal affairs office. There were no other classrooms or teachers in the building, but a district person served the class lunch from a cart each day. José implemented Interactions in the chemistry portion of his class that he typically taught three days per week for one hour, but could extend or condense his lessons since he saw his students every day. He was able to gauge their interest and engagement, and made decisions about whether to progress or whether the students needed a break.

Data collection

Curriculum implementation and professional development primarily took place during the fall of 2015. All of the weekly virtual meetings and Saturday sessions were video-recorded; while individual instructional coaching sessions were audio-recorded. Field notes were taken for each day of the summer professional learning institute. Each teacher also joined an online course management space where resources were posted, and some teachers chose to post lesson ideas, warm-ups, videos of class work, and implementation issues in the form of a blog. All blog posts were copied and recorded in field notes. Table 3.3 summarizes all the data collected.

Table 3.3: Summary of Data Collected

Data Type	Activity	Data Collected
Professional learning data	Summer Institute	Written field notes
Professional learning data	Weekly Meetings	Video-recorded
Professional learning data	Saturday Sessions	Video-recorded
Professional learning and Classroom data	Instructional Coaching	Audio-recorded
Classroom data	Teacher Blogs	Copied into field notes
Classroom data	Classroom Observations	Video-recorded
Classroom data	Teacher Interviews	Audio-recorded
Classroom data	Field notes	Typed

Data collection and case study development for Nathan and Mark were very similar. Nathan and Mark both participated in three teaching episodes during fall semester. For each teaching episode, I audio-recorded a teacher interview where I asked the teacher questions about how they prepared for the lesson, and whether they had made specific preparations for their particular students. I then visited the teacher and video-recorded a week's worth of class sessions, totaling approximately 230 minutes of instruction. Lastly, I audio-recorded a debriefing interview asking the teacher to describe successes and challenges of the lesson, about specific practices observed during the lesson aligning with inclusive 3D instruction, and whether they implemented ideas or strategies from professional learning activities. A teaching episode was recorded for Mark and Nathan about once per month. One additional observation and interview was collected in March, 2016 during Spring semester to identify what practices teachers continued to engage in once the intensive professional learning support ended, and how their ideas and practice around inclusive three-dimensional instruction changed as a result of continued use of the curriculum and the weekly professional learning community.

Due to José's alternative teaching context, his schedule of observations and debriefing interviews - and therefore his case study development - was different than that of Nathan and Mark. José taught science to his students for one hour, three days per week. However, José was not able to start using the curriculum until late October because he didn't have technology in his classroom until computers were delivered to his site. During the months of November and December, I observed a classroom session and conducted post-observation interview as scheduling permitted resulting in five 60- to 120- minute classroom observations and three debriefing interviews. José was in a unique context where he could extend or shorten his lessons as he wished, resulting in a variation in lesson times. One additional observation and interview was collected in March to identify what practices he continued to engage in once the intensive professional learning support ended. This lesson was 60 minutes in length, and was followed by a final interview. While there are less data for José, and data wasn't collected using the teaching episode format, his unique classroom context and remarkable shift in instruction add depth to this study.

Case Study Development

Third hour was selected as a "focus hour" for both Nathan and Mark because their other classes were often interrupted by tardies, breakfast, and announcements. Although Nathan's classes seemed to have fewer interruptions than Mark, I selected the third hour class for both teachers, as this was the hour with the least amount of interruptions. José only taught one chemistry section to his students a few times per week, and between November and December I visited his classroom five times for a total of five observations.

To analyze classroom data, I began by coding each classroom video by looking for instances where teachers engaged in inclusive three-dimensional science teaching including 1) positioning students as knowledge generators where students generate and evaluate ideas in class, 2) eliciting, valuing and leveraging funds-of-knowledge – students community developed knowledge that can be leveraged to explore science ideas, 3) encouraging use and sharing of student language which includes allowing students to use language they are comfortable with to explore science ideas, 4) valuing students lived experiences as evidence where students bring outside experiences into discussion, and 5) promoting use of students' critical lens to solve problems where students learn to evaluate and critique ideas and use that process in their daily lives (Kolonich, Richmond, & Krajcik, 2017). As part of this coding scheme, each feature in *The Framework for Inclusive Three-dimensional Science Classrooms* was developed into a large level code, with each element becoming a sub-code. For example, for the large level code "Positions students as knowledge generators" there were three sub-codes including "students generate and evaluate ideas using evidence". I decided to code this way so that I could see where teachers were engaging in aspects of each feature and look at whether or not the teacher engaged in all elements of the feature or just one. This provides some indication as to whether the complexity with which teachers engaged in the elements changed over time.

In Nathan's classroom, there were instances in the video where the teacher or students were speaking Spanish to one another. As a monolingual English speaker, there wasn't an easy way for me to code these portions of video. I enlisted the help of a science education researcher who situates his work in equity and who speaks both English and Spanish. Together, we spent one hour viewing and coding one of Nathan's lessons together – allowing time for questions and debate about when to include each code. Next, we watched the segments of video where students and the teacher spoke Spanish to one another. On the first pass, my colleague would provide a general synopsis of the conversation and I asked questions about the teacher's demeanor such as: "was he speaking to them in a joking way, or a serious way?". Together, we played the segment of video a second time and my colleague and I selected codes (where appropriate) for the section of video. We selected codes for Spanish-spoken segments of video together because not knowing the language, I could not code them on my own. I needed my colleague's help to know what the teacher and students were saying, and the inflection and body language used. There were no recorded instances of Spanish speaking in Mark's lessons, and I was able to code all the remaining video on my own.

Once the classroom video was coded for instances of inclusive science teaching, I wrote a summary of each class session and placed it into a case-study document organized by teacher. I kept track of all the classroom observations chronologically, and left space to include summaries of professional learning sessions, interviews, and instructional coaching sessions chronologically. Next, I reviewed all teacher interviews and instructional coaching sessions, looking for teacher talk about 1) planning or implementing three-dimensional practices that supported all students in instruction, 2) issues they were having with implementation, and 3) practices they tried in their classrooms taken from professional learning sessions. If there were particularly compelling quotes about changing practice, I transcribed those directly. I developed a summary of each interview and instructional coaching session, including transcribed quotations, and placed these summaries chronologically in each teacher's case study document.

Finally, I coded each professional learning activity for the amount of time each teacher engaged in the session by asking questions, responding to another participant, or otherwise contributing to discussion, and reviewed codes later to develop a summary of what each teacher chose to respond to and talk about. For example, in one professional learning community session, both Nathan and Mark contributed to the conversation; Nathan referred directly to a reading and read a quotation to the group, while Mark instead shared an anecdote from his teaching in conversation. I developed a short summary of how each teacher engaged in each professional learning session and included them chronologically in the case-study document.

Once the case study document was complete, with chronological summaries of all activities, I then developed a summary for Nathan and Mark of each teaching episode directly from that document. Episode summaries included the summaries of everything that happened between the pre-episode interview and the post-episode interview. This allowed me to review what practices were discussed during professional learning sessions to determine whether I could see evidence of teachers using professional learning discussions to make changes in their teaching. During data analysis, I often used the case studies and episode summaries to direct me back to audio/video data that I then transcribed and included in the findings section. Case studies and episode summaries for Nathan and Mark were developed very similarly. The major difference in case study development between Nathan/Mark and José is that José's case study did not include teaching episodes or episode summaries, while I was able to include teaching episode summaries for Nathan and Mark due to the large amount of data I collected in their classrooms.

Case Study Analysis

After case study development was complete, I analyzed the case studies to address my research question *"what aspects of the professional learning program did teachers engage with, and how do they enact their learning in the classroom?"* I looked within each case chronologically to identify patterns in how teachers engaged during professional learning sessions, and how learning from the professional learning activities showed up in teacher interviews and in their classroom instruction. In particular, I tried to link specific instruction aligning with the features from *The Framework for Inclusive Three-dimensional Science Classrooms* per my codes to teacher participation in the PLP. At some points in the semester, there were professional learning sessions immediately followed by an in-class observation, and I focused my efforts at these points in the semester. In doing so, distinct patterns emerged for each teacher, and I present examples of each pattern over the course of the semester for each teacher.

Findings

Patterns Within Each Case

Nathan. Examination of Nathan's case summary (abstract in Appendix B) for evidence of how he interacted with the professional learning activities and incorporating his learning in the classroom revealed a clear pattern that I characterized as an "action-research approach". Nathan grounded his discussion in the professional learning community and the Saturday sessions in the readings, using excerpts from the book study and from research articles during discussion. Nathan often quoted excerpts, including page numbers, and also referenced them in pre-episode and post-episode interviews when talking about his instructional changes. Considering Nathan's background as a former Ph.D. candidate, it makes sense that he would draw his instructional evidence from readings in this way. In particular, Nathan chose a specific instructional reform that we read about on September 19th during the Saturday session to implement and revise over the course of the semester. The article, titled *The driving question board: A visual organizer for project-based science* (Weizeman, Schwartz, and Fortus, 2008), detailed the research and use of a DQB to elicit and organize student ideas. When reviewing the video, most of the coding for inclusive, three-dimensional science classrooms seemed focused around implementation of the DQB. While the Interactions teacher materials also offered supports for teachers in implementing a DQB, reading the article helped Nathan understand why the DQB was a useful tool to support student understanding.

After reading the article about the DQB during the Saturday session, Nathan started implementing and adapting his use of it in class. His first attempt at the DQB was putting a driving question on the board and having students use post-it notes to add ideas or questions to it. However, students struggled to see the board from far away and didn't interact with it much. Next, Nathan made a digital version of a DQB in Padlet©, where students could write on digital post-its and move them around to group ideas that were similar or place the questions into categories. While students could now see and interact with the board, they still struggled to pose questions related to the overall driving question. In Nathan's second teaching episode, he works to address the issue of students struggling to pose good questions, and I include excerpts here from this episode as an example of his action-research approach.

This data was collected during Nathan's second teaching episode which took place from October 20th – 23rd 2015, about one month after reading the DQB article for the first time. In our pre-episode interview, Nathan reflected on his implementation of the DQB as a digital tool, and some changes he made to it based on student feedback. He also talked about struggling to get students to engage with the DQB, indicating that it was really difficult for them to ask good questions around the driving question.

> *"I presented the DQ – it was basically that activity in the article I read where [students] put their ideas on post-its and we re-organize them. I just did it electronically." "In the one class [administrator] was observing I had one student who kept writing obscenities in Spanish on the DQB so I had to stop the activity." "Since then, I have had every student sign up for an account so that I can track their progress. Each time I do the DQB*

I have been tweaking it a little bit. I think I have the mechanics now, it's the discussion I need to improve on." (Interview 10.15.2015)

In the same interview, Nathan refers to a reading in the book study that included a teacher vignette modeling engaging students in discussion around a driving question before introducing it.

> *"I like the idea of having the driving question for them to refer back to and get them thinking about the topic. In chapter 6 [NGSS for all Students] I noticed the teacher started with a discussion about background knowledge about gases and let the kids talk for a while and then threw out the driving question. I have to do some thinking and research before Wednesday and think about another approach to the DQB."* (Interview, 10.15.2015).

During my classroom observation on October 21st, Nathan engaged his students in a discussion around the DQB (as we discussed in the interview) and started the next investigation by posing the driving question to the class. Nathan asks, *"What are all materials made of? That's a big question right? We might have smaller questions to ask around this."* Some students shouted out ***"atoms"***[8] and ***"components"*** Nathan then asked students, *"Ok, so what is an atom?"* this time more students started shouting out answers: ***"protons," "electrons," "a nucleus"*** and Nathan pushed them further: *"Ok, then what is a proton? What's a proton made of?"* Students laugh, one shouts out, ***"I have no idea!"*** Nathan responds: *"So I am throwing out some examples of further questions we could ask. It sounds like you might already have some background knowledge, so what further questions do you have?"* He then asks students to each post one question on the DQB that would further understanding of the topic, "What are all materials made

[8] Student responses are bolded for clarity between speakers

of?" Students seem more engaged after this discussion and are typing out their digital post-it notes (Classroom observation, 10.21.2015).

The next evening, Nathan presented screenshots of the DQB to the professional learning community in hopes of getting feedback on his technique. His question for the group was, "How can we improve how we are using the DQB, and also how we use it once it is developed?" Nathan shared that he had the students pose smaller questions related to the driving question on post-it notes in Padlet© (Figure 3.1). Next, he had students organize the sub-questions into categories during a class discussion where they talk about each question and which other questions are similar to it. Finally, Nathan asked students to look at each category and develop a summary question that addressed everything in the category. Nathan then took these category level questions that students develop and made a concept map (Figure 3.2) for the students to refer back to.

Figure 3.1: Nathan's Third Hour DQB Presented 10.22.2015

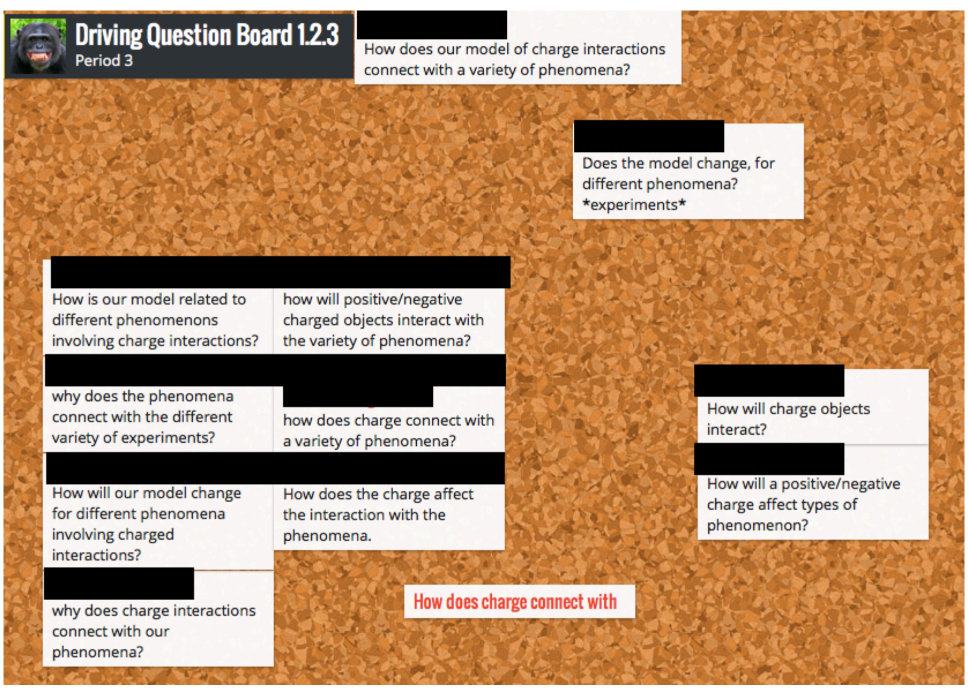
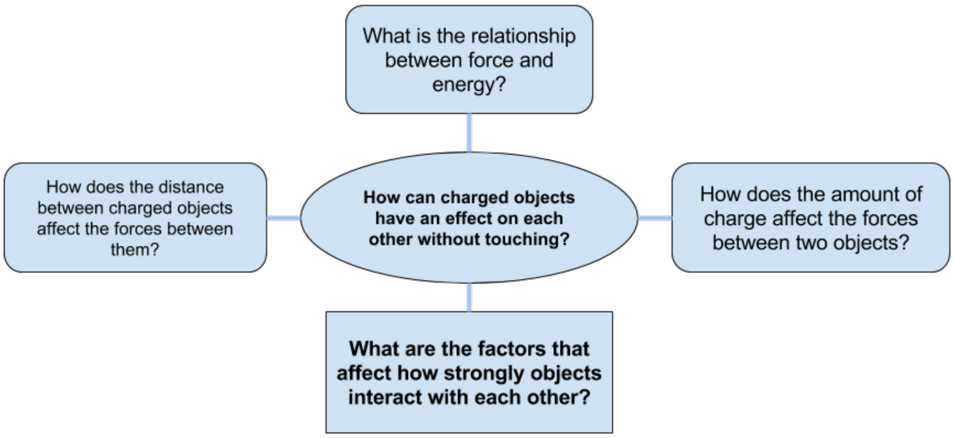


Figure 3.2: Nathan's Third Hour Concept Map Presented 10.22.2015



During the session, Mark suggested allowing students to work in groups first to develop questions before putting them on the board – sort of a think, pair, share to give time to think before they had to place an item on the board. Nathan agreed that developing an activity would help give students some direction, and said he could also give points for the activity (which he liked). José suggested connecting the DQB to a journaling activity, or to have students look at the questions together and decide which ones are going to "make the board." Towards the end of the session, Nathan thanked everyone and closed with the comment that students need more scaffolds to pose questions. *"The board I started yesterday I will come back to tomorrow and will use some organizational things to help them. They have written questions that are scattered all over the board, and I will give them better headings to organize them under. Maybe that would help give them more direction than asking questions related to a question"* (Professional learning, 10.22.2015).

The next day in class, Nathan engaged students in the DQB on Padlet© again and, as he stated, made categories for students that relate to the larger question to scaffold question development. *"I made categories for you that relate to the larger question because I noticed some of you struggling to come up with questions related to the larger question. I came up with* *categories and I would like you to develop questions that will help you learn more about each category. First, read your question and then put it into these categories that are in each of the four corners of the board."* (Classroom observation, 10.23.2015). However, during the post episode interview, Nathan reflected that it didn't work as well as he had hoped, and that his next plans were to develop an activity to use with the DQB so that it is ready when he starts the next investigation (Interview, 10.23.2015).

After reading about the use of a DQB during the September 19th meeting, Nathan started implementing one in his classroom and worked to perfect its use over the course of the school year. The original article describes the DQB as a physical board where students can place post-it notes with questions and ideas, but Nathan decided to develop a digital version of the DQB to avoid problems he experienced with the original design such students struggling to see everything. However, Nathan then struggled to engage his students with the digital DQB and implemented a strategy he read about during the book study, where a teacher first engaged students in discussion around a driving question before introducing it. Nathan tried out this discussion strategy in his next lesson, and students seemed more engaged. Development and revision of the DQB was so important to Nathan that he also presented it, along with implementation challenges, in our weekly professional learning community. Other teachers in the group offered suggestions for how to engage students with the DQB by allowing them to talk in groups and to make decisions about what questions will make the board. However, Nathan didn't take up those suggestions. Instead, he chose to scaffold question development by providing students with categories of questions, and in his next lesson, he used that strategy with his students.

During the remainder of the semester, Nathan made a few more changes to the DQB, including having the students work on revising their questions as they got new information, and making the DQB discussions a routine part of the start and end of each class. During the November 19th Saturday session, Nathan presented his modified DQB to the group of teachers as an instructional tool that prompted discussion and Nathan continues to share his refined DQB with new science teachers in the district. When I visited Nathan again in March, his students were comfortable with the DQB and engaged with it readily. The class had a conversation out loud about the post-it notes that were being developed and moved around on the screen – allowing students to participate either out loud or through their writing. In the March interview, Nathan reflected that he thought the DQB benefitted student learning, but that it was difficult to evaluate exactly how, or who benefitted more. He also said that it is a teaching tool he plans to continue using to structure his science classes.

Mark. Looking across Mark's case summary (abstract in Appendix C) for evidence of how he interacted with the professional learning activities and incorporated his learning into the classroom revealed a clear pattern which I characterized a "reflective practice approach." Mark was already in the habit of audio-recording his instruction on his phone and listening to it during his commute each day, and was excited to take advantage of instructional coaching to get another perspective on his teaching. Mark was the most active in the instructional coaching sessions, and he took advantage of every opportunity to review his teaching with the instructional coach – and used those discussions to make changes in his instruction. While I recorded the instructional coaching sessions for research purposes, Mark also recorded the sessions to review during his commute to work, just as he did his lessons. During our professional learning community sessions, Mark often used anecdotes of his teaching, or reflections from instructional coaching sessions, to drive the conversation, prompting others to reflect on their teaching too. This pattern of instruction, facilitated reflection in the coaching session, discussion of reflection in professional learning community, and change in instruction came up several times in Mark's case study across the semester.

In Mark's first teaching episode, which took place from October 6th – 8th 2015, he decided to try out some of the discussion prompts that we were learning about in the professional learning community to elicit students' ideas and access their funds-of-knowledge. On the morning of my first observation, Mark mentioned to me that he was very tired, and had been reviewing videos of his teaching to prepare for this observation. He also mentioned that there was some "self-doubt" creeping in, and he was nervous about his lesson. I reminded him, *"it's teaching, we are always evolving and growing,* and that *"we are often our worst critics"* (Field Notes, 10.6. 2015). During the lesson, Mark had students read through the experimental procedure and conducted a short discussion about the roles of each group member, and the steps of the experiment before proceeding. *"Let's hear from Karen; how do you find the mass, what are some steps?" "Where do you walk to if you want to find the mass?"* Karen answers, ***"To the back."*** *"to the back, like to the window? Do you look outside?"* [Students laugh] *"What do you have to have to find the mass?"* Karen answers ***syringe."*** *"What do you do with the syringe?"* Students answer, ***"put it on the scale."*** *"Ok, and then what are you going to do with the numbers?"* students answer, ***"hit zero."*** *"No, you already hit zero, and then you are going to place the syringe on top, and who will you tell the numbers to?"* No one answers. *"You are going to tell the numbers on the scale to number 2s in your group"*. (Observation, 10.6.2015). Mark wants to make sure the students understand the instructions for the activity before proceeding, but rather than asking the students to look back at their notes, he told them the steps that they couldn't remember. This pattern continues throughout the lesson, where Mark allows the students time to share their ideas and look in their notes, but transitions back to telling the students the answer when they get stuck.

During our instructional coaching session after class, Mark reflected on the lesson. He was very disappointed in himself for the way he facilitated discussions in the lesson, and we spent a lot of time talking about that.

> *"I was sort of scared with the class discussions in period one because, what if I couldn't explain it? Or if someone asked a question I couldn't answer? If we are in discussion, I am supposed to guide them to build their answers off another answer off another answer… I didn't want to lose their trust. It was really hard to get out of the box and say ok, lets discuss this. It's my first go with this curriculum and… yeah. I don't know if you noticed this with [3rd hour] but I just started telling them what to know in some parts. I was like oh my god, this is like… heretical."* (Professional Learning, 10.6.2015).

After his reflection, I pushed Mark to see his lesson as less of a failure and more of an opportunity. I said, *"While there is no right or wrong for students, we want all their ideas… there also isn't a right or wrong for you. Keeping that growth mindset for yourself as a teacher is very important."* Mark seemed to really resonate with this statement, because we had talked about having a growth mindset for student learning in our professional learning community. Later in the conversation, Mark reflected back to this comment, *"It really takes a lot of courage to put yourself out there. I really want to have the growth mindset – when you said that it made a lot of sense, like 'that would make me grow' - trying something new."* Throughout the remainder of the session, we talked about the difficulty of facilitating discussions when the students aren't talking. As a potential solution, we discussed strategies for making students feel more comfortable talking in class, such as allowing them to share all their ideas without judgment, allowing them to express themselves in ways that are comfortable to them, and getting them to talk to each other in small groups before engaging in small discussion (Professional learning, 10.6.2015).

The next time I came to observe, Mark's outlook had completely changed. I recorded my observation of his demeanor in my field notes before class. "Mark seems rejuvenated today and much more positive about everything. He said that our conversation was very helpful, and that he recorded it. Mark is back! Today's lesson I saw all the excitement and energy come back that he had in the beginning" (Field notes, 10.8.2015). In this lesson, Mark used some of the strategies that we had discussed in our instructional coaching session to get students talking. In this observation, Mark's class was ending the investigation, and he asked students to use evidence they collected to answer the question "What are all materials made out of?" Students first discuss the answer in small groups, and then report out what they discussed in the larger group--a strategy from our instructional coaching session. Mark then used discussion prompts such as *"What makes you think that? "Does anyone have a similar/different idea?"* and *"What further evidence can you cite that explains this?"* to push students further and further in conversation. When the students got stuck toward the end of the conversation, Mark asked them to talk in their groups instead of telling them the answer, this time assigning each group to think about evidence collected for a particular type of material – solids, liquids and gases. Students reported out their answers to the class, and the evidence provided was collected on the screen in the front of the room (Observation notes, 10.8.2015).

Mark made some significant changes in the way he facilitated student discussion during his first teaching episode by reflecting on his instruction with the instructional coach, and taking some suggestions offered to promote student engagement during discussion. Mark really seemed to resonate with the concept of keeping a growth mindset for himself, just as he does for his students, and he came into his second observation rejuvenated and more positive. In reviewing Mark's case study, a cycle emerged which included an interview, observation, instructional coaching session, Mark's individual review of observations and coaching sessions, and ultimately an instructional change. This cycle repeated throughout the semester, with Mark making significant progress first in facilitating discussions in class, and then in integrating literacy into science later in the semester.

José. Looking across José's case summary (abstract in Appendix D) for evidence of how he interacted with the professional learning activities and incorporating his learning in the classroom revealed a pattern that I characterized a "collaborative learning approach." José was the most active during our weekly professional learning community sessions, and valued the experiences and advice of the other teachers in the group (as indicated in his interviews). This makes sense, as José and his students were isolated from other teachers and classrooms at their alternative school site location. José often posed instructional questions to the teacher group, and he repeatedly tried out practices discussed in the weekly meetings as seen during classroom observations. Although he was an experienced teacher, José enjoyed bouncing ideas off other teachers and hearing about the Interactions activities they enacted with their students. José not only valued his professional learning community of fellow teachers, but also valued development of a collaborative community in his own classroom. José expressed gratitude for our focus on moving towards equitable science classrooms, stating: "This is the way I was taught to teach, that I used to teach – but somehow we got lost along the way. It feels good to get back" (Interview, 11.11.2015).

Although José was not able to start using the curriculum with his students until a few months into school, he was active during professional learning sessions and started using the strategies that we had discussed in his classroom right away. During our October 29th 2015 weekly meeting, we reviewed chapters 9 and 11 of the *NGSS for All Students* book focused on English Language Learners, and students in alternative education. José was very active in this session, both asking other teachers for advice in implementing the curriculum, and in sharing his experience as the only alternative school teacher in the group. José mentioned that, as an alternative teacher, one of his biggest struggles was to get students talking to each other, and he was struggling to get them talking to one another about the activities. Some ideas that came up during the session were to use discussion prompts to get students engaged in the lesson, and using sentence starters for English Language Learners to help them with their writing.

Toward the end of the session, José reflected on his circumstance teaching in the alternative setting, he talked about how much he enjoyed getting to know his students, and having the freedom to extend lessons or cut them short, and that he appreciated the Native American community that came in to support students, "*They are decorating for Halloween right now and we are going to have a meal. It's really neat, they have skeletons and coffins all around the room and spider webs hanging from the ceiling. They are always doing things like that to make the students feel comfortable here."* However, José had some challenges to share with working in the alternative setting too.

> "*It's a really interesting model, but the down side is that you miss that collaboration. We have meetings, but they are heavily structured and we don't get to talk. Like, I used to go eat lunch with my department in my original school and we would meet after school to*

talk if we needed to. Although we don't see admin either, which I guess is maybe a positive."

The very next day, October 30th 2015, was my first observation in José's classroom. In this lesson, José used probing questions and discussion prompts (a strategy we talked about in our weekly meeting the night before) to get his students talking about the tape activity, with questions like, *"What happened when the two pieces of tape had different letters?"* and to another student: *"Is that what you saw too?" "What happened when the pieces of tape had the same letter?"* The students became immediately engaged in the discussion. Later in the lesson, when students struggled, José prompted them to ask one another for help, even if that meant meeting students from another group. José was successful in using discussion prompts in this lesson to elicit his student's ideas, and prompted them to talk with one another when they had questions, instead of always asking the teacher.

Later in the lesson, students were testing whether a water bottle had an effect on small pieces of paper when it was uncharged, and then when it was charged. The students cleaned the bottle with the alcohol wipe and waved it over the paper, and were confused because nothing was happening. A student, Kate[9], read the directions and tried it again. ***"Mister, why is nothing happening?" "What is supposed to be happening?"*** José replied, "*Hmmm, I don't know… you should try it again",* giving students the power to develop their own knowledge. Another student at a different table, named Vincent, said that nothing was happening because the materials were uncharged. ***"We didn't do anything to it, it's not charged"*** A third student, Ellen, didn't understand, so Vincent tried explaining again. ***"We didn't add anything to it or do anything to it, so it is uncharged"*** Kate said ***"maybe if we rubbed it like we did the balloon, then it would***

[9] Students are represented with pseudonyms.

be charged and do something" She started vigorously rubbing the bottle on her head (holding just the cap) and held it over the pieces of paper. The tissue jumped toward the water bottle and stuck to it, and the students started laughing. Vincent tried to do the same thing, but his hair didn't work as well, so the students kept rubbing the bottle on Kate's hair to see how much of the tissue paper they could pick up (Classroom observation, 10.30.2015). In his interview, José expressed how happy he was that his students were talking to one another and collaborating in class – particularly because this group of students was unsuccessful in school in the past. *"I was so happy the group did such a great job talking to one another. In the alternative program, our challenge is pulling them out of their comfort zone and using each other as resources"* (Interview 11.11.2015). José also mentioned the importance of high-risk students seeing themselves as successful, and said that when students collaborate and solve problems together in class they are successful.

Later in the month, during our November 19th professional learning community meeting, Autumn was presenting student work to the group, and José noticed something in the work she presented that he was also seeing with his own students (See Figure 3.3). "*In question 18, it seems their concept of interaction is only when it's attractive – they don't consider repulsion to be an interaction. To develop an explanation, they really need to have a better idea of what 'interaction' means"* (Professional learning, 11.19.2015).

Figure 3.3: Autumn's Sample Student Work Presented 11.19.2015

Question 18

How do your models explain your observations of the interactions between two charged objects, or a charged object and uncharged object?

Our experiments showed that a negative charge and negative charge object do not interact and that a positive charge and negative charge do. The same with an uncharged object with an uncharge. They repel and a charge and uncharge attract.

The next day, I observed José's class and saw him addressing this situation directly with his students. José starts out with a review discussion of everything that the students did in Investigation One, since today was the wrap-up activity for the whole investigation. He asked students what happened with the wig and tapes, and students volunteered their answers. José took this opportunity to start a conversation about what constitutes an "Interaction." Through the discussion, students reached a consensus that objects not doing anything are not interacting, so if something happens - anything (whether attracting or repelling) then it is interacting (Classroom observation 11.20.2015).

José maintained his focus on facilitating meaningful discussions with his students, and although there were some days it was difficult to get students talking, he was able to develop an inclusive learning community where students were talking, laughing, and engaged in science learning. José talked openly about his appreciation for our professional learning community, and often used strategies discussed in the sessions to improve his instruction. When he had a particular struggle, José brought it up in discussion and asked some of the other teachers (who were further along in the curriculum) for advice.

Discussion

In this study, three teachers accessed different aspects of an equity-focused Professional Learning Program and made changes to instruction in ways that met the needs of their specific situation. These case studies provide further support for research stating that sustained, research-based professional learning programs are important for teacher learning (NRC, 2015; Wilson, Schweingruber, & Nielsen, 2015), and that providing professional learning programs with multiple entry points for diverse teacher learners maximizes program effectiveness (Desimone & Garet, 2015 Wei, Darling-Hammond & Adamson, 2010). This study brings equity-in-science research into the era of NGSS, and pushes teachers, teacher educators, and instructional coaches to consider how the next generation of science can go beyond implementing inclusive teaching strategies. Instead, our PLP asked teachers to integrate inclusive science instruction as guiding pedagogy with 3D instruction to best meet the needs of non-dominant students in their specific context. While Nathan, Mark, and José didn't necessarily implement all elements of inclusive 3D science instruction as described by Kolonich, Richmond, and Krajcik (2017), they were able to integrate aspects of the guiding pedagogy with learning from specific aspects of the PLP to make instructional changes.

Critical Features of Equity-focused Professional Learning Programs

In facilitating the equity-focused Professional Learning Program, I learned about what did – and did not – work for teachers. This is difficult – at times emotional work for teachers and instructional coaches, and requires building strong, positive relationships for the program to be successful. As Davis (2003) writes, "change can be a difficult and complex process" (p. 27) and teacher learning activities must begin with teacher knowledge and beliefs (Davis, 2003). Teachers are generally used to a certain level of autonomy, and teachers expressed that they felt very vulnerable when being observed. Forming strong relationships with teachers and taking a non-evaluative stance in my coaching (Taylor, 2008) helped keep observations and debriefs a productive part of the PLP. As an instructional coach, I learned that it was important for me to always be mindful of teachers social, emotional, and cognitive needs – just as we ask teachers to do with students. This can be a heavy emotional load for instructional coaches as it required me to make decisions about when conversations about instruction, or that may challenge their teaching philosophy, would be most productive to have. For example, if a teacher expressed that he was feeling defeated and worn out, I may have saved a conversation dissecting a particular practice or student interaction until a later time when he was feeling more confident. I also learned that keeping the PLP flexible and responsive to teacher's immediate and specific needs was an important aspect of our PLP. While this makes it difficult to scale such a program, it was crucial to harness in-the-moment learning experiences. However, the payoff for committing to such a program is profound. I believe our program helped teachers form better relationships with their students, and developed stronger science classroom communities.

Implications for the field moving forward

This study has promise for stakeholders moving forward to increase the power and effectiveness of PLPS. First, it is important for teachers to recognize the importance of participating in a sustained PLP to effect change, and to acknowledge that the work will be difficult and emotional. At times, the amount of sessions or the thought of an outside person observing instruction can seem overwhelming, but if teachers are willing to fully participate, instructional coaches can facilitate instructional change. Second, instructional coaches must take into consideration how difficult and emotional the work can be for teachers and for themselves. Attending to social, emotional and cognitive needs, and maintaining flexibility within the program are crucial for teacher learning in an equity-focused PLP. Program developers, teacher educators, and educational researchers must acknowledge that different teachers learn differently and express their learning in different ways – just as students do. Providing multiple entry points through varying activities and acknowledging that teachers may change instruction in different ways that still positively impacts the classroom community is important. This study provides three examples of ways that teachers may interact with an equity-focused PLP and implement their learning in the classroom: an action-research approach, a reflective practice approach and a collaborative learning approach. Future work should continue to examine patterns of teacher learning and implementation to better help teacher educators facilitate instructional change.

My hope is that this work will encourage teacher educators and researchers to consider the different ways in which teachers learn best and integrate that understanding into future equity-focused PLPs. All of the things we want teachers to do in their classrooms to promote inclusive communities and facilitate learning are also things that we must do in our teacher learning programs to promote the same thing.

APPENDICES

APPENDIX A: Consultancy Protocol for Examining Student Work

Figure A.1: Consultancy Protocol for Examining Student Work

National School Reform Faculty

Harmony Education Center

www.nsrfharmony.org

Consultancy

Adapted for Examining Student Work

Developed in the field by educators affiliated with NSRF.

Time
At least one hour

Roles
Presenter (whose student work is being discussed by the group)
Facilitator (who also participates)

Steps

1. The presenter gives a quick overview of the student work. S/he highlights the major issues or concerns, and frames a question for the consultancy group to consider. The framing of this question, as well as the quality of the presenter's reflection on the student work and related issues, are key features of this protocol. (5 minutes)

2. The group examines the student work. (5 minutes)

3. The consultancy group asks clarifying questions of the presenter — that is, questions that have brief, factual answers. (5 minutes)

4. The group asks probing questions of the presenter — these questions should be worded so that they help the *presenter* clarify and expand his or her thinking about the issue or question s/he raised for the consultancy group. The goal here is for the *presenter* to learn more about the question s/he framed or to do some analysis of the issue s/he presented. The presenter responds to the group's questions, but there is no discussion by the larger group of the presenter's responses. (10 minutes)

5. The group talks with each other about the student work and related issues in light of the questions framed for the group by the presenter. What did we hear? What didn't we hear that we needed to know more about? What do we think about the question and issue(s) presented?

   Some groups like to begin the conversation with "warm" feedback — answering questions like: "What are the strengths in this situation or in this student's work?" or "What's the good news here?" The group then moves on to cooler feedback — answering questions like: "Where are the gaps?" "What isn't the presenter considering?" "What do areas for further improvement or investigation seem to be?" Sometimes the group will raise questions for the presenter to consider ("I wonder what would happen if…?" or "I wonder why…?"). The presenter is not allowed to speak during this discussion but instead listens and takes notes. (15 minutes)

6. The presenter responds to what s/he heard (first in a fishbowl if there are several presenters). A whole group discussion might then take place, depending on the time allotted. (10 minutes)

7. The facilitator leads a brief conversation about the group's observation of the process. (10 minutes)

Protocols are most powerful and effective when used within an ongoing professional learning community such as a Critical Friends Group® and facilitated by a skilled coach. To learn more about professional learning communities and seminars for new or experienced coaches, please visit the National School Reform Faculty website at www.nsrfharmony.org.

Protocol from: https://www.nsrfharmony.org/system/files/protocols/consult_stud_work_0.pdf

APPENDIX B: Case Study Abstract for Nathan

Nathan taught at a large public high school and was able to start using the interactions curriculum right at the beginning of the school year. I was able to observe Nathan's teaching during three teaching episodes where I held a pre-episode interview, observed about 250 minutes of continuous instruction and held a post-episode interview. During Nathan's first teaching episode, he expressed excitement over using the curriculum because it was set up to get students thinking and expressing their ideas in words. I noticed right away that his classes were totally silent. Students would open their computer to work, but it was very difficult for Nathan to get students offering ideas or contributing in discussion. Often, it was the same group of students who would contribute, and they seemed hesitant to do so. Nathan tried to get students to volunteer ideas in large group discussion by using some of the curricular prompts, but it didn't seem to have much of an effect. Much of the interaction between students and teachers fell into the "IRE" format of Initiate, Respond, evaluate. This was something the students were more used to and would contribute something. During our lunchtime discussions, Nathan mentioned that he struggled to allow students to work together and believed that they should work independently. This was because he felt that often it would just be one student doing the work and the other students copying. However, the final lesson in the first teaching episode included a small group activity. Nathan didn't have high hopes for it. During this lesson, I used the video camera to zoom in on one group of three girls at the back of the classroom. They were developing an experimental procedure together. Later, Nathan and I watched the video together during an instructional coaching session to see how students engaged in group work, and he was very surprised – both by the amount of work they were able to accomplish, and that every single member of the group contributed to the conversation. This seemed to establish a shift in Nathan's teaching and he allowed small group work more often.

During the second teaching episode, Nathan was still trying to get students to offer ideas in class so that the class has something to work with in discussion. More students seemed to contribute more often, but many were still silently listening. Nathan tried a few strategies from the professional learning sessions such as think-pair-share, and having them submit ideas to the teacher as an exit ticket. The strategy that really seemed to work for Nathan was projecting student work in front of the class during discussion. This way, he could get at some of the ideas from the quieter students and bring that into discussion. However, the main thing Nathan worked on during this teaching episode was trying out the Driving Question Board (DQB) which was a strategy that the group read about in a professional learning session. Nathan really liked the idea of a DQB and thought that it would really promote student engagement and sharing of ideas. He had some ups and downs, and made tweaks to the DQB and how he used it in class. It seemed to take the students some time to get used to. Instruction in this episode also seems to be teacher-led, but it seems as if Nathan is trying to model for the students how to contribute in class and engage in the scientific practices. Nathan is modeling for them how the NGSS-Classroom will run. However, Nathan expressed in his post-episode interview that he felt that he talked more than usual and wanted to flip that dynamic. During this episode, I continued to see an increase in the amount of time Nathan allowed students to work together, and the varied ways he structured small group work. Towards the end of the teaching episode, Nathan had switched to a digital DQB where students could post ideas anonymously online, and move ideas into categories. There was some trial and error with this version too, but Nathan stuck with it.

Nathan was pretty quiet during the professional learning sessions, but always had thoughtful contributions and the other teachers seemed eager to learn from his experience. When Nathan did contribute, he often cited quotes from articles or book chapters as evidence to support his idea. During one of the student work sessions, Nathan presented a DQB that he had developed with his students to get feedback from the group on how to make it a more meaningful experience for them. Nathan also shared a more perfected version of his DQB in November during a face-face Saturday session. He was able to work out most of the kinks with the DQB during his third teaching episode, and felt comfortable sharing his work with the rest of the group. This was helpful as Nathan was the only teacher to take-up that particular strategy. In the third teaching episode, Nathan tried out some activities that he developed around the driving question board. I noticed that while students still came into class and logged into their computer silently, they immediately went to the digital DQB and began writing down ideas and questions to be grouped into categories. While students were typing and organizing ideas, many students would have an out-loud conversation. I thought it was an interesting way to capture ideas from all the students – allowing some to discuss the topic out loud while some students typed their ideas anonymously. This way, everyone's ideas could be taken up in large group discussion. Over the semester, Nathan made gains with respect to three-dimensional instruction in that he supported students in 3D learning more often. His supports also became more complex, first focusing on the practices and then integrating the crosscutting concepts later (perhaps due to his own comfort). Nathan made slight gains in amount of time spent on inclusive teaching practices, but his implementation seemed sporadic in nature. However, his focus on eliciting ideas from students to use in discussion was consistent throughout the semester, and I believe he had success with that using the digital DQB.

APPENDIX C: Case Study Abstract for Mark

Mark taught at a large public high school and was able to start using the Interactions curriculum at the beginning of the year. Mark expressed that he was excited to start using the curriculum and transform his teaching. He struggled early in the semester to get the materials that he needed, but was able to get them sent to his school from the local science center. Due to some scheduling issues, I wasn't able to get in and see Mark until early October for his first teaching episode. By then, Mark had established his classroom norms and community, and students were used to working together in groups of four. Mark had a large average class size (55 students) and space in the room was limited. In the first episode, Mark asked me to watch for how well he listened to his students. He was concerned about this because he felt that sometimes he got excited and added in his own thoughts and ideas, and really wanted the student's thoughts and ideas to shine. Mark also mentioned that he had been recording his teaching and using it to improve his instruction to prepare for my observations. He had been working very hard to incorporate the inclusive three-dimensional practices we discussed in our professional learning sessions. Mark said that one of his biggest struggles was allowing students to take control of the discussion, especially in situations where he doesn't have a good grasp on the content. One of the things that I noticed right away about Mark's teaching was how structured everything was. Each group had a number, and each group member had a letter so that he could quickly assign tasks to particular students. For example, he would nominate "Cs" as the materials person for the group. Later, he might ask the "Bs" to offer an idea. This strategy seemed to work well for his students. They always knew what the task was and how long they had to work on it. My sense was that this was a product of his large class size.

Mark was very active during instructional coaching sessions. He often had an agenda planned of things to talk about, or requests to look at something together. Mark even requested additional Instructional coaching sessions, so we tried to meet or talk 1-2 times per week. In the first episode Mark really focused on facilitating in depth discussion with his students, and expressed frustration that he wasn't able to let the students take control of the discussion. His fear was to be in a situation where a student asked a question he couldn't explain because he didn't want to lose their trust. In reflecting on his lessons, Mark realized that at some points in the lesson – he reverted back to just telling the students what to know. We talked about the fact that change takes time and while there aren't right or wrong ideas for students, there aren't right or wrong ideas for teachers either. I encouraged him to have a growth mindset for himself, as well as his students, and to take it one step at a time. In the next lesson, Mark seemed much more relaxed and was able to incorporate more talk moves to get students talking. At one point in the lesson, students were unable to reach a consensus through discussion and instead of telling them the answer, he asked them to vote for an idea on their computers in real time. While at times the conversation sort of wandered, Mark was able to reign it back in and definitely made progress on his goal of letting the students share ideas to guide the conversation. In our post-episode interview, Mark reflected on how hard he had been working, exclaiming that it felt like his first year of teaching all over again. He also said that even though it was hard work, he was already seeing positive changes in his classroom.

During Mark's second teaching episode he asked me to watch for how much he was scaffolding students and to talk about a balance of scaffolding and letting students wrestle with ideas. In this lesson, some new topics were introduced – such as the crosscutting concept of scale, proportion, and quantity. I noticed that Mark had mostly made the switch to a facilitator role, allowing students to introduce ideas, collect evidence, and come to a consensus, but Mark did switch into a lecture role again to introduce the new crosscutting concept. It seemed like there was more lecture in the first lesson to introduce new practices and crosscutting concepts, and then periods of discussion where students could try out using those practices and talking about the crosscutting concepts. There was also an external observer in the room – his department chair – which may have had an effect on lesson style. In the second lesson, Mark again seemed more relaxed and it was a fun lesson! Students were simulating Rutherford's experiment with a shoebox and laser, and really seemed to enjoy the lesson. Here, Mark projects student answers and asks the class to look at them and determine which answers contained evidence. Students started to see patterns in the answers and developed a sort of rubric for claim and evidence. Mark also started trying to relate science topics to things students are familiar with, or asking them to do it either in discussion, or on paper. In our post-episode interview, Mark talks about how hard it was to let students wrestle with a wrong idea. He really wanted to tell them the right answer, but held it in. He also mentioned that he really wants to make his classroom more equitable and was frustrated that it was taking so much time to perfect some of the strategies we learning in our PLP.

During the third teaching episode, Mark took a break from the curricular activities and developed a lesson for students that would scaffold the scientific practices. By now, students had learned and had experience with all eight, but were starting to get them confused. One of the activities Mark had students do to scaffold understanding of the practices was having students identify where in a piece of science reading the author was engaging with or discussing one of the eight practices. Students were able to highlight things like asking questions, carrying out investigations, and analyzing data. Mark also began integrating writing into the curriculum to support student understanding of the specific practice “claims, evidence, reasoning”. Students worked on a 3-4 paragraph claims, evidence reasoning essay for the driving question “Are there such things as electrons?” Mark encouraged them to share evidence from class, and from outside of class. Students then traded essays and looked for claims, evidence, and reasoning in the work of their peers. Mark exhibited tremendous growth over the semester, first with giving up some authority and allowing students to drive discussion with their ideas, and then in scaffolding scientific practices by incorporating literacy into his instruction. Students were able to express ideas verbally or thorough their writing, and it was the students who shaped these ideas into classroom knowledge. Mark attributes his success to the curriculum and the professional learning program because he “learned to ask questions and not to give answers”.

APPENDIX D: Case Study Abstract for José

José was not able to begin using the Interactions curriculum right at the beginning of the school year because he was waiting on the computers the district had promised for his classes. I visited him many times before he began curriculum implementation in November to get to know him, his classroom and his students. On my first visit, I noticed that the students were somewhat standoffish toward me, and not interested in the science curriculum. A few students expressed to José that they wanted to continue working on their contracts rather than take science as a class. I also noticed that because José was teaching in an office building at a "school site" within the community, there were no science supplies available – including lab tables and sinks. José was the only teacher at his school site and was not able to borrow or trade supplies. I made a point to check in with and see José more often to make sure that he had everything he needed. The more I visited José's class, I noticed that many people were involved in the education of students at this site. Native American students from the local university came in 3 times per week to tutor students and offer support. The community sponsor of the school came in once per month with food to share with the students and even threw a Halloween party for them. José was even able to forge an agreement with the local gym so that students could go there and get their physical education in. While the continuation school didn't have the typical school community, there was definitely a sense of community at this site.

I observed five lessons in José's class during November and December 2015. In his first interview, José mentioned that his main focus for his teaching during this time was to get the students talking to each other. During the first observation, José began using some of the talk moves and other strategies that we discussed in the professional learning sessions to get students talking. The students seemed skeptical and hesitant at first, but with persistence over the semester José was able to get them working together. There were 6 students who participated in the Interactions class, and José split them into two groups of three. He first worked to get them talking to one another within their groups, and during the later lessons José encouraged students to share or ask for help from the other group. Where the students really seemed to get excited about their learning was anytime there was a hands-on activity. To me it almost seemed as if they forgot that they were at school, and took the time to explore and try out all the ideas they were thinking of. Students were really engaged by the hands-on activities and those also played a role in encouraging students to talk to each other. When an activity didn't work, or gave them a strange result, students asked each other for help. It was really amazing to watch over those two months as these students who really hadn't met before, due to them working individually on contracts, form a science classroom community that was collaborative.

José was very active during the professional development sessions, particularly the evening virtual sessions where he could bounce ideas off other teachers and asking them for ideas. I got the impression in the beginning that José was worried that he wouldn't fit into the group because he was working with alternative students in a very different context, but soon found that a lot of his successes and challenges mirrored that of the other teachers in the group. In addition, the other teachers really valued his experience at the same time that José valued their experiences and points of view. I noticed during José's third observation that he was using some of the strategies in class that were brought up during the professional learning community session from the week before! This trend continued during José's fourth and fifth observations. José seemed to either share a challenge and ask for advice from teachers, or listen to a challenge another teacher had and incorporate feedback from the group into his teaching. In the two months that I observed José, I felt that his class has changed drastically. Students became more comfortable trying out ideas, sharing ideas, and asking each other for help. Analysis of José’s classroom teaching showed that the amount of time he spent engaging in practices that supported students in inclusive three-dimensional learning increased over the course of the semester.

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CHAPTER 4: STUDY THREE

Supporting Urban Science Teachers in Implementing a Project-based Curriculum Using Inclusive Three-dimensional Instruction

Abstract

Three-dimensional science instruction requires educators to support students in meeting learning goals, while also ensuring all students have opportunities to participate and be successful in class. To achieve this goal, teachers need quality curricular materials that support three-dimensional learning, and knowledge of instructional approaches that provide all students opportunities to learn science. In this study, I explore how inclusive three-dimensional instruction supports teachers in implementing project-based, three-dimensional science curriculum to best support their students. Five teachers from Los Angeles Unified School District implementing a project-based curriculum participated in a year long professional learning program focused on inclusive science instruction, and two teachers were selected for case study analysis. Data collection included classroom observations, interviews, field notes, and student work. Findings indicate that both teachers made instructional decisions that supported their students in project-based learning very differently - yet in ways that met the needs of their specific teaching context.

Introduction

Science instruction that engages students in learning to develop usable knowledge requires both rich and meaningful curricular materials, and an instructional style that is student-focused. Research shows that "project-based learning has the potential to help all students – regardless of culture, race, or gender – engage in and learn science" (Krajcik & Shin, 2014 p. 279; Lee & Buxton, 2010). Project-based Learning (PBL) engages students in exploration of phenomena where they have opportunities to ask questions, discuss and try out ideas, and challenge the ideas of others (Krajcik & Shin, 2014). Rich, educative curricular materials – materials that support teacher learning as well as student learning – can serve as a support for teachers in implementing project-based learning in their classrooms while supporting new pedagogical strategies for future use (Davis & Krajcik, 2005). Research shows that curricular materials often influence the instructional decisions that teachers make on a daily basis (Jones & Tarr, 2007; Robitaille, & Travers, 1992) but teacher knowledge, beliefs about teaching, and their alignment with curricular materials can have an impact on how those materials are implemented in the classroom (Davis & Krajcik, 2005).

Although educative curricular materials are intended to support teachers in learning new pedagogical strategies that align with curricular goals, teacher learning is best supported with additional approaches such as face-to-face professional learning workshops and online discussions (Putnam & Borko, 2000). In a previous study, I developed a year-long professional learning program (PLP) to support teachers in developing inclusive teaching practices while implementing a project-based learning curriculum called Interactions in high school physical science classrooms. The inclusive three-dimensional (3D) teaching approach emphasized is intended to support teachers in developing inclusive classrooms as a first step in working toward equitable science teaching (Kolonich, Richmond & Krajcik, 2017). In that study, we found that different teachers engaged with and made use of different aspects of the PLP which illustrated the need for multiple entry points in teacher professional learning for diverse teacher learners. In this study, I shift the focus from teacher learning *per* se to examine the research question "How does inclusive science instruction support teachers in implementing a curriculum aligned with PBL to best meet the needs of their classroom context?"

Conceptual Framework

Three-dimensional science instruction requires educators to support students in meeting learning goals that focus on students making sense of phenomena or solving problems using disciplinary core idea, crosscutting concept and scientific and engineering practices, while also ensuring all students have opportunities to participate and be successful in class. To achieve these goals, teachers need quality curricular materials that support 3D learning, and knowledge of instructional practices that provide all students opportunities to learn science. In this study, teachers participated in a PLP focused on inclusive 3D instruction while also implementing a curriculum aligned with project-based learning in their classrooms. In this section, I first explore inclusive 3D instruction as the primary instructional focus for teachers, and then describe the curriculum aligned with project-based learning called Interactions that teachers implemented in class.

Inclusive Three-Dimensional Instruction

Unequal opportunities to learn science between dominant and non-dominant students in school are a widely recognized and researched topic (Calabrese Barton, Tan & O'Neil, 2014; Carter Andrews, Bartell, & Richmond, 2016; Milner 2010). These disparate opportunities are a direct result of inequities within the K-12 education system. Promoting more equitable science classrooms, where each individual student is given the opportunities needed to succeed in science, will require teachers to develop inclusive science learning environments where students feel safe to share and critique ideas, and where they believe/feel they are a valued member of the science learning community. Current reforms in science challenge teachers with transitioning to phenomena-driven, three-dimensional science instruction, and discuss inclusive teaching "strategies" as a way to engage students in science (NGSS Lead States Appendix D, 2013; NRC, 2012). However, I reframe inclusive science instruction not as a collection of strategies to promote student engagement, but as an instructional reform to changes the way we teach science and support teachers in promoting equitable science classrooms (Kolonich, Richmond, & Krajcik 2017).

Developing inclusive 3D classrooms where all students feel safe to share and evaluate ideas requires teachers to attend to linguistic, cultural, and emotional aspects of student learning (Anderson, 2007). In a previous study (Kolonich, Richmond, & Krajcik, 2017), I proposed a Framework describing inclusive 3D science instruction to serve as a resource for teachers, teacher educators, and researchers in facilitating instructional changes. *The Framework for Inclusive Three-dimensional Science* Classrooms reframes inclusive science instruction as a guiding pedagogy rather than a collection of strategies to engage students, and relies heavily on funds-of-knowledge as a conceptual tool (Calabrese Barton, Tan, O'Neil, 2014; Moll, Amanti, Neff, Gonzalez, 1992). The Framework is made up of five elements that integrate inclusive pedagogies with three-dimensional instruction: 1) positions students as knowledge generators, 2) elicits, values and leverages funds-of-knowledge 3) encourages using and sharing of student language, 4) values students lived experiences as evidence, and 5) promotes use of students' critical lens to solve problems. Each of the five elements includes clarification and descriptions from classroom observations depicting what teachers and students do in classrooms that incorporate each element in instruction.

Teachers in this study participated in a PLP focused on inclusive 3D instruction while implementing a curriculum aligned with project-based learning in their classrooms. I developed this program in the previous study by first reviewing research on effective teacher learning programs and leveraging that research for my particular focus on inclusive science instruction. Many scholars have taken up the five features of effective teacher learning programs including 1) a focus on content knowledge, 2) engaging teachers in active learning, 3) a coherent program, 4) sustained duration, and 5) collective participation (Desimone & Garet, 2015; Luft & Hewson, 2014; Wilson, Schweingruber, & Nielsen, 2015). Drawing on this research, I developed a sustained program to support teachers in developing inclusive 3D pedagogies and integrating them with their project-based curriculum that spanned one year. Professional learning activities were 1) initial summer institute, 2) analyzing student work during weekly sessions, 3) reviewing research-based instruction during weekly sessions, 4) Saturday professional learning sessions, and 5) individual instructional coaching. The resulting program engaged teachers in over 50 hours of contact time over the 2015-2016 school year.

Teachers first participated in a summer institute where the learning goal was to introduce 3D instruction and establish a professional learning community. Teachers engaged in model teaching and debriefing episodes, explored inclusive 3D instruction and developed and revised models. Once school started, teachers began attending a weekly, virtual professional learning community where they engaged in two activities: 1) exploring student thinking through analysis of student work to inform instructional decisions (Whitworth & Chiu, 2015), and 2) Exploring research based student scaffolds to inform instruction. During the first semester, teachers also attended two in-person Saturday sessions where they evaluated student models, dug deeper into 3D learning and project-based learning, and presented teaching tools and strategies used to other teachers. Finally, each teacher participated in instructional coaching sessions which included classroom observation and debriefing episodes, structured teacher reflection sessions and co-analysis of teaching videos – activities that support instructional change (Stewart, 2014; Wilson, Schweingruber, & Nielsen, 2015). The goal of instructional coaching was to promote a growth mindset for their students and for themselves. While each of the sessions were structured, I also designed each session to be flexible so that the program could be iterative and responses to teacher's individual needs. For example, if a problem came up in a weekly virtual meeting, I could alter plans for the next in-person session to address or revisit that problem.

The two elements from *The Framework for Inclusive Three-dimensional Science Classrooms* I selected to focus on in this study were 1) positions students as knowledge generators, and 2) elicits, values and leverages funds-of-knowledge. The reason for this focus was twofold: 1) both elements are heavily grounded in funds-of-knowledge as a conceptual tool for teachers - a central goal of the PLP; and 2) both elements were supported to some extent in the Interactions curriculum. Element one, *positions students as knowledge generators,* provides opportunities for students to generate ideas and validate or discard them using evidence collected in class discussions. Teachers do not evaluate ideas as incorrect or correct, but prompt students to evaluate their own ideas by using evidence and reasoning. Teachers can scaffold this type of analysis by asking students what is similar or different in student responses, or by challenging them to analyze the data collected to form a consensus. By *eliciting, valuing, and leveraging funds-of-knowledge*, teachers not only foster student engagement, but also affirm student identities and foster appreciation for different world-views (Calabrese Barton, Tan, & O'Neil 2014). Figure 4.1 includes clarification and sub-elements of these two Framework elements.

Figure 4.1: Elements from The Framework for Inclusive Three-dimensional Science Classrooms

Description: How well does the science teaching work to support students by valuing ideas, cultural knowledge and linguistic differences? Does the classroom work as a community to develop an environment where everyone feels safe, supported and encouraged to express ideas?

1.1 Positions students as knowledge generators

Clarification: During classroom discussion, the teacher does not evaluate ideas as correct or incorrect, but encourages students to provide evidence for ideas. Students evaluate each other's ideas using evidence and develop explanations through discussion.

1.1.1 Students generate ideas and evaluate ideas using evidence.

1.1.2 Students (as a community) develop evidence-based explanations through discussion.

1.1.3 Teacher consistently validates student's contributions, attributing ideas and knowledge to students, and using their ideas in discussion.

1.2 Elicits, values, and leverages funds-of-knowledge

Clarification: Funds-of-knowledge do not have to be from one specific place, but can be from pop culture, peer culture, family culture, or community culture. The intent of using funds-of-knowledge goes beyond promoting engagement or discussion to include valuing and legitimizing who students are and what they already know as important for developing classroom knowledge.

1.2.1 Teacher provides space for students to share cultural or community developed knowledge in the classroom.

1.2.2 Teacher encourages students to share their funds-of-knowledge and lived experiences.

1.2.3 Teacher leverages funds-of-knowledge contributed in discussion to promote science learning.

Interactions and Project-based Learning

Three-dimensional learning supports students in making sense of phenomena by integrating crosscutting concepts (CCs), disciplinary core ideas (DCIs), and scientific and engineering practices (SEPs) (NGSS Lead States, 2013; NRC, 2012). Similarly, project-based learning (PBL) emphasizes that knowing and doing cannot be separated, and that engaging in knowing and doing together supports students in explaining phenomena and solving problems (Krajcik & Shin, 2014). Krajcik and Shin (2014) describe six features of PBL including 1) driving questions, 2) learning goals that align with standards and assessment, 3) participation in scientific practices, 4) engaging in collaborative activities, 5) using technology, and 6) creating tangible products that address driving questions. This study focused on inclusive three-dimensional instruction while teachers implemented Interactions, developed as a 3D science curriculum also designed with the six features of project-based learning (Damelin & Krajcik, 2015; https://learn.concord.org/interactions).

Interactions is designed to scaffold student understanding toward a unit-level driving question and unit and lesson level learning goals expressed as performances. To do so, the investigations and activities in each unit also have driving questions that incrementally build students understanding of the observable phenomenon. An example of a unit-level driving question is "*Why do some clothes stick together when they come out of the dryer?*" This is a broad, unit-level question that is then scaffolded with more fine-grained driving questions at the investigation and unit level such as "*What are some examples of some things that stick together and other things that don't?*" Each activity also lists learning goals for students that are built from the NGSS performance expectations. An example of a learning goal is "Students will collect and interpret data to identify patterns in the way that charged objects interact with each other." Students then participate in hands on activity and simulations, engaging them in science and engineering practices, like analyzing and interpreting data, to work towards the learning goal.

Learning in Interactions is driven by collaboration between students, facilitated by discussion to develop a consensus understanding of the phenomenon based upon evidence and reasoning. Discussion prompts are provided for teachers throughout the curriculum to support rich collaboration through discussion. Finally, Interactions specifically supports students in the practice of modeling and target student models are provided for teachers in each activity to guide student understanding through the development and revision of models. Students develop and revise models in an online portal (or with pencil and paper) and also manipulate digital models – simulations – to explore causes for phenomena too small to be seen. In using technology to develop, revise, and manipulate models, students are developing tangible products of their developing understanding (Damelin & Krajcik, 2015).

The Interactions teacher materials were designed to be educative for teachers, meaning that they are intended to promote teacher learning as well as student learning (Arias, Davis, Marino, Kademian, & Palinscar, 2016; Davis & Krajcik, 2005). One way that educative curriculum functions as a cognitive tool is to help teachers learn new ideas and add them to their repertoires of practice. Interactions does this by not only introducing new pedagogical approaches that teachers can use to support all students in learning, but also by describing the rationale for each approach. This allows teachers to situate the instructional approach into their practice and integrate the idea more generally, rather than just in the particular situation presented in the curriculum (Davis & Krajcik, 2005; Lave & Wenger, 1991). Although educative curriculum can be an important support for teachers, supporting educative curriculum with additional professional learning activities is more effective than using one learning approach alone (Davis & Krajcik, 2005; Lyons et. al., 2014). In the previous study, the educative curricular materials in Interactions served as one important learning support for teachers within the professional learning program.

Interactions Unit One

The Interactions curriculum was designed as a three-dimensional science curriculum supporting student understanding of submicroscopic interactions. It was intended as a 9th or 10th grade physical science curriculum after which students would move into biology or other life science courses. During this study, teachers implemented unit one of Interactions in their classroom for the 2015-2016 school year. The driving questions for unit one as mentioned above is "*Why do some clothes stick together when they come out of the dryer?*" During the unit, students complete investigations and activities to develop a model of electric interactions that explains electrostatic phenomena, and a model of atomic structure to build an understanding of the mechanism behind charged objects. To build these target models, students gather evidence and reach consensus through discussion to identify which evidence supports the phenomenon and should be added to their models. By the end of the unit, students should have an electrical model of matter that includes 1) interactions between positive, negative, and neutral objects, 2) that distance and amount of charge affect the strength of attractions 3) there is more than one way to charge an object, and 4) charge is due to electron transfer. Students' atomic models should include 1) a dense nucleus with protons and neutrons – surrounded by electrons, 2) atoms are charged when they have an unequal amount of protons and electrons, 3) every element consists of a different atom and 4) atoms are too small to be seen with an unaided eye (Damelin & Krajcik, 2015). A full description of unit one, including driving questions for each investigation and activity are included in Appendix A.

Curriculum Analysis for Inclusive Three-dimensional Learning

To determine whether Interactions fully integrated the three dimensions as intended, I conducted an analysis of Interaction unit one using the *Evaluating the Quality of Instructional*

Products (EQuIP) rubric. I used criterion one of the EQuIP rubric titled alignment to the NGSS, which requires 1) evidence of all three dimensions; 2) evidence that all three dimensions are braided together, and 3) evidence that learning is coherent across lessons. I focused on Unit one of Interactions because that is the unit teachers implemented during the study, and used the EQuIP criteria to analyze each activity for alignment. Excerpts from the curriculum gathered as evidence indicate that each activity in unit one integrates the three-dimensions of NGSS as intended. Evidence of all three dimensions are present in each activity, the activities make use of the three dimensions and braid them together in instruction, and the intended learning goals are coherent across activities. My curriculum analysis, as shown in Appendix B, indicates that Interactions is a fully aligned three-dimensional curriculum that shows coherence within and among lessons as designed. This is important as the teacher materials in Interactions are designed to be educative for teachers, and we have evidence that indeed those educative materials are aligned to NGSS. Thus, the 3D educative teacher materials served as one important support for teachers in implementing inclusive 3D instruction.

To determine whether the teacher materials support teachers in developing inclusive three-dimensional instructional moves, I examined the teacher's guide for unit 1 using the five elements from *The Framework for Inclusive Three-dimensional Science Classrooms* including 1) positions students as knowledge generators, 2) elicits, values, and leverages funds-of-knowledge, 3) allowing use and sharing of student language, 4) values students' lived experiences as evidence, and 5) promotes use of a critical lens to solve problems. Analysis indicated the instructional materials for unit one often support teachers in 1) positions students as knowledge generators including all sub-elements of this practices. Specific prompts are included for teachers asking them to step back and allow students to figure out the phenomenon. The instructional materials provide supports for sub-element one of 2) eliciting, valuing and leveraging funds-of-knowledge in that the curriculum does provide general prompts for eliciting knowledge from students. However, the analysis included in Appendix C revealed that Interactions tends to focus on eliciting prior school knowledge, and does not offer specific prompts for eliciting knowledge from outside of school. There is nothing to prevent teachers from doing so, just not specific teacher prompts supporting that practice. Interactions rarely supports teachers in 3) allowing use and sharing of student language and 4) value student's lived experiences as. Finally, Interactions supports teachers in sub-element one of 5, i.e., promotes use of a critical lens to solve problems in that students are often asked to evaluate each-others work based on evidence. While there is no support for taking that critical thought to issues in the community, there is nothing preventing a teacher from doing it on their own.

Methods

In this study, I emphasize the importance of pairing pedagogies focused on providing opportunities for all students in science with quality curricular materials that engage students in exploring phenomena. With this in mind, the research question driving this study was as follows: *How does an inclusive 3D approach support teachers in implementing a project-based science curriculum in ways that best meets the needs of their students and classroom context?* I used a multiple case study approach (Yin, 2014) and selected two teacher participants for analysis based on the amount of data collected. Data sources include curriculum documents, audio-recorded interviews with two teachers, and video-recorded classroom observations. The remainder of this section includes information about the participants and context, case study development, and data analysis techniques.

Participants and Context

Role as a participant observer. Although I approached this study as a researcher with particular questions in mind and a data collection plan, I was also an active participant in interviews, classroom observations, and professional learning activities. I categorize my role as that of a participant observer – a researcher who also participates in the research context (Glesne, 2011). When observing teachers, I mostly recorded video and took field notes describing the classroom and what the students were doing, but I also interacted with students to answer their questions or to help them move forward in an activity. Despite my participation in the classroom, I took great care to engage with students in a way that was fitting to the classroom environment, and never undermined the authority of the teacher. As a participant observer, I cannot separate myself from the research context, and there are both benefits and drawbacks to this style of research. One benefit is that I was able to observe everything going on in the classroom as it was happening and also interview teachers directly afterward based on my observations. One drawback is that I may have made decisions that contributed to teacher and student learning, but may not have been beneficial for research. My main focus with this work was to support teachers in inclusive three-dimensional instruction, and I acted in the moment as I saw fit with this focus in mind.

Nathan and Mark. For this study, I am focusing on the classrooms of Nathan and Mark to examine how the instructional changes they implemented impacted the classroom environment, and ultimately student learning. I discuss Nathan and Mark here together to highlight the similarities and differences in their experience and context. Nathan was an experienced physics and engineering teacher with over 20 years of teaching and administrative experience. He received a bachelor's degree in biology, a master's degree in educational administration, and had been pursuing a Ph.D. focused on educational assessment. Nathan taught three physics classes on a block schedule with each class lasting 84 minutes and meeting two-three days per week. Mark was a mid-career chemistry teacher with eight years of teaching experience. His bachelor's degree was in English, but he attained additional certification for chemistry after his graduation. Mark taught four chemistry classes and one honors chemistry on a block schedule with each class lasting 120 minutes in length meeting two days per week. Both teachers taught at similar high schools in southern Los Angeles serving predominately Latinx students of low socio-economic status. In both Nathan and Mark's classroom, there was a high percentage of English Language Learners (ELLs) at varying levels of English proficiency. The first language for most ELL students in Nathan and Mark's classrooms spoke Spanish as a first language, and in both classes I observed students translating for each other. Both teachers implemented Interactions (only offered in English) in all of their classes. Nathan and Mark both started the curriculum at the beginning of the 2015-2016 school year and completed unit one at the end of fall semester, and unit two at the end of spring semester.

I selected Nathan and Mark because both participated in three teaching episodes that spanned a full semester, providing ample classroom observation data for analysis. Each teaching episode included a pre-episode interview where I asked the teacher questions about how they prepared for the lesson, whether they made specific preparations for individual students or groups of students, and what they wanted me to focus on during my observations. This interview was followed by approximately 230 minutes of continuous classroom observation and was also video recorded. I chose to do this so that I could be sure to capture entire lessons with beginning and closing activities. During class, I also recorded and typed field notes describing what was going on in the classroom, teaching that incorporated strategies from our professional development sessions, and anything that wouldn't be captured on tape (conversations students were having etc.). Finally, I followed up the instruction with a post-episode interview where I asked the teacher questions about what successes and challenges they had, and about attempts or missed opportunities to implement inclusive three-dimensional practices that I observed. For each teacher, the teaching episodes represent instruction from the beginning, middle, and end of the semester.

Data Collection and Analysis

In a previous study, I developed a case study for each teacher that spanned all three teaching episodes over the semester to examine how teachers interacted with a professional learning program and put their learning into practice. In this study, I am zooming in on Nathan and Mark's final teaching episodes to determine how their implementation of *positions students as knowledge generators* and *eliciting, valuing and leveraging funds-of-knowledge* supports project-based learning in ways that meet the needs of their specific context. I focused specifically on teaching episode three for Nathan and Mark because it took place at the end of the semester when each teacher had the most experience implementing inclusive 3D science instruction.

To analyze the data, classroom video from teaching episode three was coded by looking for instances where teachers engaged in aspects of these two elements. I also included labels for these codes aligned to the sub-elements to provide specific information. For example, I might code a portion of classroom teaching "eliciting, valuing, and leveraging funds-of-knowledge", but I would also include one or more labels on that code such as *"Teacher provides space for students to share cultural or community developed knowledge in the classroom."* Using the sub-elements as labels for each code provided information about whether the teacher implemented certain aspects of the Framework element, or embraced all aspects of it.

Elements that characterize project-based learning were also identified and coded. These included 1) driving questions, 2) learning goals that align with standards and assessment, 3) participation in scientific practices, 4) engaging in collaborative activities, 5) using technology, and 6) creating tangible products that address driving questions. I looked for instances of classroom practice where inclusive 3D instruction and features of PBL were implemented simultaneously, and developed teaching excerpts that combined summaries of interviews and field notes in chronological order.

The findings are organized by first giving some context for the activity analyzed for each teacher including what the students had been learning up to this point, what the learning goals and driving question of the investigation were, and what specifically students were doing in class. Next I include a description of teaching that combines PBL and inclusive 3D instruction based on simultaneous coding, and a discussion of how this combination of inclusive 3D teaching and PBL curriculum worked to support each teacher's specific goal and school context. A short summary of how these inclusive three-dimensional instructional practices were supported is included at the end of the section for each teacher

Findings

Nathan

Lesson context[10]*:* In the very first interview that I had with Nathan, he reported that his biggest struggle was to get students expressing their ideas "*That's where I think I've been disappointed in the past is trying to get students to ask questions. They are not used to having to express ideas in words. I have to keep pushing to try to get more out of them, and it's kind of a new experience for them"* (9.15. 2015). Getting students to voice ideas and ask questions was a

[10] Curriculum information taken from teacher materials at https://learn.concord.org/interactions

goal Nathan revisited over the semester. This lesson takes place during unit one in investigation three. The driving question for this investigation is "What are all materials made of?" In a previous lesson, students explored this driving question by first participating in a thought experiment where the teacher gave each student a piece of paper and asked them whether it can be cut in half over and over again indefinitely. In the second activity, students conducted an investigation measuring liquids including alcohol and water. Students saw that when you combine 5ml of alcohol and 5ml of water, it does not equal 10ml of fluid. These activities are designed to provide students with evidence for the particle nature of matter - all materials are made out of small particles that cannot be seen with the naked eye.

This activity has a goal similar to the second activity in that students gather evidence for the particle nature of matter, only this time they are exploring gases instead of liquids. The driving question for this particular activity is "*Is the particle model always better?*" This lesson began with a review of the driving question board (DQB) - a visible ongoing collection of student ideas and questions related to the phenomena - where the teacher emphasized that different models can be used to explain the same phenomena, provide both models explain (use all evidence) equally well. Students then performed an activity with a syringe to determine whether or not air has mass by weighing a syringe on a scale when it is open, and then placing a stopper over the top of the syringe, pulling the plunger back to create a vacuum, and weighing that syringe as shown in Figure 4.2. After calculating the difference, students used a computer simulation to explain the aspects of the activity that are unobservable.

Figure 4.2: Creating a Vacuum in the Syringe

Picture taken from: https://learn.concord.org/interactions

Classroom observation. Nathan worked during the semester to develop a digital DQB to get students asking questions and to collect their ideas. His idea for using the DQB was based on an article he read as a part of the professional learning program, but Nathan continually modified and tweaked his version of the DQB based on the experiences he had using it in class. The purpose of the DQB was to create a place where students could post and organize ideas, and then use those ideas to drive discussion. Nathan's DQB was different than the one suggested by the article and supported in the curriculum in that Nathan's DQB was digital and offered students an anonymous space. Often Nathan started class by having students log into the DQB and he facilitated a class discussion based on the ideas, pictures, links, and models present on the board. Students determined if there was sufficient evidence to support ideas, and what further information was needed to form a consensus. Often the class discussion would take place out loud as students were moving digital post-it notes and pictures around in the online space, or linking similar ideas together. The observation described here takes place during Nathan's final teaching episode where he had worked out kinks with both the digital tool used with students, and also planning discussion around use of the tool.

In this lesson, Nathan asked students to recall their previous activity with the liquids and use the evidence they obtained to answer the question "*does air have mass?*" He projected the

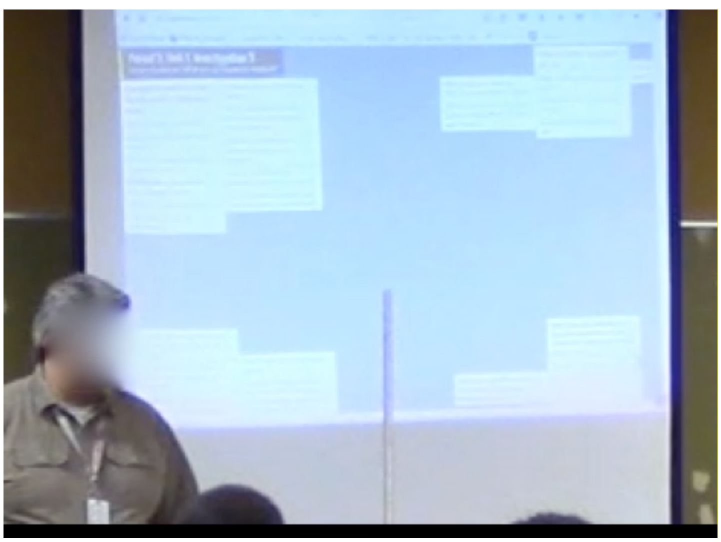
DQB on the screen at the front of the room (shown in Figure 4.3) while students logged in. Nathan prompted students to make a claim as to whether or not air has mass in the online DQB, attach the evidence they had to support their claim, and describe the reasoning linking the evidence to the claim. However, students immediately struggled and didn't know what to do, so Nathan scaffolded their understanding by using the DQB to organize these three components of an explanation.

He first made a large box at the top of the screen that said "*Does air have mass?*" He then asked the class "*There are two potential answers to the question - and each potential answer corresponds with a claim. What are the two potential answers?*" One student raised his hand and said ***"The two claims are that Yes air has mass, and No air does not have mass."***[11] Underneath the large box, Nathan drew a line down the middle of the DQB and wrote "Yes air has mass" on one side and "No air does not have mass*"* on the other side. *"While I was waiting for what is a claim, some of you started including something other than a claim here. Some people started giving me evidence."* Nathan then asked students to arrange the evidence recorded from the previous day into the claim the evidence supported. *"Pick the claim that you think is true right now based on the data we collected - either air has mass or air doesn't have mass - and I want you to think of one piece of evidence that you have from your life that you observed to support that claim. List that evidence underneath the claim. Your reasoning then would describe how the evidence you listed supports the claim. Place the evidence under the claim, and the reasoning next to the evidence."* Some students then began moving pieces of data recorded from the previous class and creating new post-its with questions and ideas. However, some students struggled and weren't interacting in the online space – perhaps because they were unsure of what

[11] Student responses are bolded for clarity between speakers

to do, or not confident to display ideas in front of their peers. *"I'm going to give you an example. I put a lot of air on the scale and the scale said the air weighed 10lbs."* ***"That didn't happen! [laughs]"*** *"You are right, but it is the type of thing you could put as evidence for air has mass."* Nathan continued on to scaffold student understanding of reasoning. *"The reasoning then is how the evidence supports the claim. If something has weight according to the scale, it must have mass because weight is the effect of gravity on mass"* From my observation point, I could see lots of new post it notes popping up on the screen and students were moving them around. Nathan then walked around the room to assist individual students who were still struggling (Observation from November 6, 2015).

Figure 4.3: Nathan Projecting the Driving Question Board in Class



After the air mass discussion using the DQB, the students take a few minutes to draw a model predicting what will happen when they weigh a syringe with and without air in it. Then, students work in small groups with the syringe both with and without air to gather more evidence for whether or not air has mass. The students struggled with the activity because they forgot to measure all of the same pieces on the scale for both measurements leaving only the air as the changing variable. After some time, Nathan asked one student to come to the front of the classroom and complete the measurement for all the students and told the class they should help him make sure he is completing the measurements correctly. Once the students had their measurements, they moved on to the next part of the activity (Field notes, 11.6. 2015).

Classroom analysis. In this lesson, Nathan integrated aspects of Framework element two; Elicits, values and leverages funds-of-knowledge with three features of project-based learning; 1) centering instruction around a driving question, 2) engaging students with technology to support learning, and 3) engaging students in scientific practices. Nathan developed an online driving question board (DQB) where students could post questions and ideas anonymously while having classroom conversations. The anonymous nature of the online DQB potentially reduced stress associated with voicing ideas in class, and gave students who might be nervous an avenue for sharing ideas to be taken up in classroom discussion. Nathan implemented the first two aspects of Framework element two as shown in Figure 4.4.

Figure 4.4: Analysis of Nathan's classroom November 6th 2015

1.2 Elicits, values, and leverages funds-of-knowledge

Clarification: Funds-of-knowledge do not have to be from one specific place, but can be from pop culture, peer culture, family culture, or community culture. The intent of using funds-of-knowledge goes beyond promoting engagement or discussion to include valuing and legitimizing who students are and what they already know as important for developing classroom knowledge.

1.2.1 Teacher provides space for students to share cultural or community developed knowledge in the classroom.

- In using the anonymous, online DQB, Nathan provided space for students to share any knowledge that brought to class – including funds-of-knowledge.

1.2.2 Teacher encourages students to share their funds-of-knowledge and lived experiences.

- Nathan encouraged students to share evidence from their lives by saying: "*I want you to think of one piece of evidence that you have from your life that you observed to support that claim*"

1.2.3 Teacher leverages funds-of-knowledge contributed in discussion to promote science learning.

- I did not observe evidence of Nathan leveraging funds-of-knowledge to promote science learning in this lesson.

While I didn't see evidence of Nathan leveraging funds-of-knowledge in this lesson, it would be a logical next step in facilitating discussion around the DQB. This lesson may serve as a snapshot of Nathan's growing understanding of eliciting, valuing and leveraging funds-of-knowledge. The online DQB also promotes three features of project-based instruction: centering instruction around a driving question "What are materials made of?", engaging students with technology to support learning, and engaging students in scientific practices by having students provide evidence for their claims. While the driving question is provided to teachers and supported in the educative teacher materials, the DQB suggested is a physical board where students write their ideas on sticky notes. Nathan developed an interactive, online DQB to meet the needs of his particular classroom and students. In this case, Nathan's quest to find ways to elicit student ideas from quiet students prompted him to make an online DQB, which also supported the features of project-based learning.

Comparing this lesson to the educative curricular materials for this lesson (Appendix D), I notice that the discussion Nathan carried out with students around the DQB was also different than the example provided in the curriculum. The curricular materials suggest that teachers should facilitate student discussion about the particle and continuous nature of matter, leading to a consensus that different models can be used to represent the same phenomenon. In addition, the only support for teachers in developing inclusive three-dimensional learning environments is a prompt to "Be careful not to judge students' responses; instead, encourage students to share a variety of ideas." However, Nathan made the decision to specifically prompt students to include evidence from their everyday lives, encouraging them to share funds-of-knowledge and lived experiences.

In the curricular materials, there also isn't a prompt for teachers explaining what to do if the students are unable to collect consistent data. Nathan could have given the students sample data, or conducted the syringe again as a demonstration so that all the students would get the same data. Instead, Nathan engaged students in the practice of carrying out investigations by calling a student the front of the classroom to conduct the experiment and prompted other students to help him - allowing them to share ideas and make corrections together. In doing so, Nathan engaged students in the scientific practice while validating that what students already know and can do as important for classroom learning.

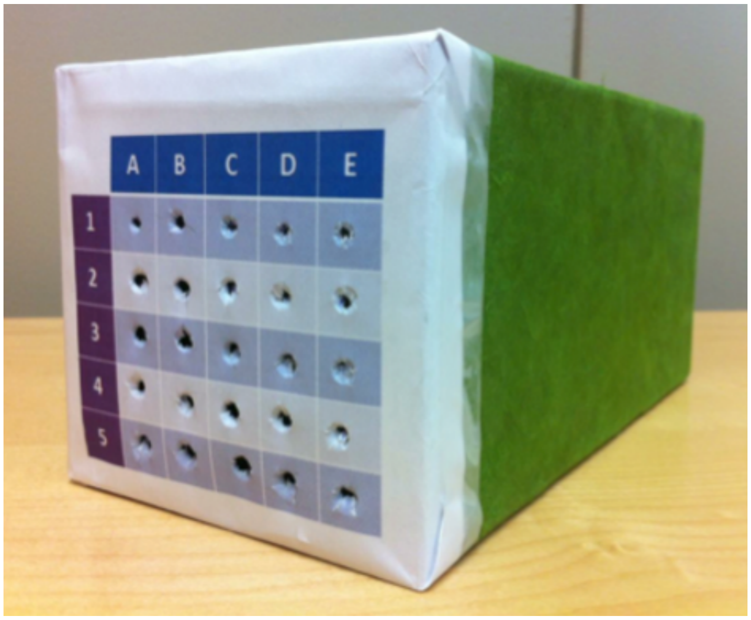
Mark

Interactions lesson. This activity takes place in unit one investigation four and the driving question for the investigation is "*What are nature's building blocks?*" In a previous lesson, students explored this question by participating in an activity where they explore the history of the atom and the relative size of atoms by comparing them to known objects. The overarching goal for this investigation is for students to gather evidence for the overall structure of the atom – that there is a densely packed nucleus in the center, and small, fast moving electrons on the outside.

The driving question for this activity is "*If you can't see it, how do you know it is there?*" Since atoms are not something students can visualize, the lesson begins with a discussion about how useful indirect evidence for unobservable phenomena is compared to direct evidence for observable phenomena. Students then participated in the activity that simulates Rutherford's gold foil experiment where alpha particles shot at a piece of gold foil were either blocked, deflected, or passed straight through based on the nature of the material. This teacher-led activity, called "The Mystery Box", gives students the opportunity to collect indirect evidence. First, the teacher creates a mystery box by making a box that is open on one side, and punches holes through the opposite side that are labeled across the top and across the side as shown in Figure 4.5. Next, the teacher places an unknown object inside the box and shines a laser through each of the holes as a demonstration. Students then recorded on graph paper in the online portal[12] where the laser goes through the holes, where it is deflected, and where it is stopped from going through. Students used this data to try and guess what object was hidden in the mystery box, similar to how Rutherford had to use indirect evidence to determine the structure of atoms.

[12] Students using the interactions materials record their answer in an online portal giving teacher immediate access to their data and information.

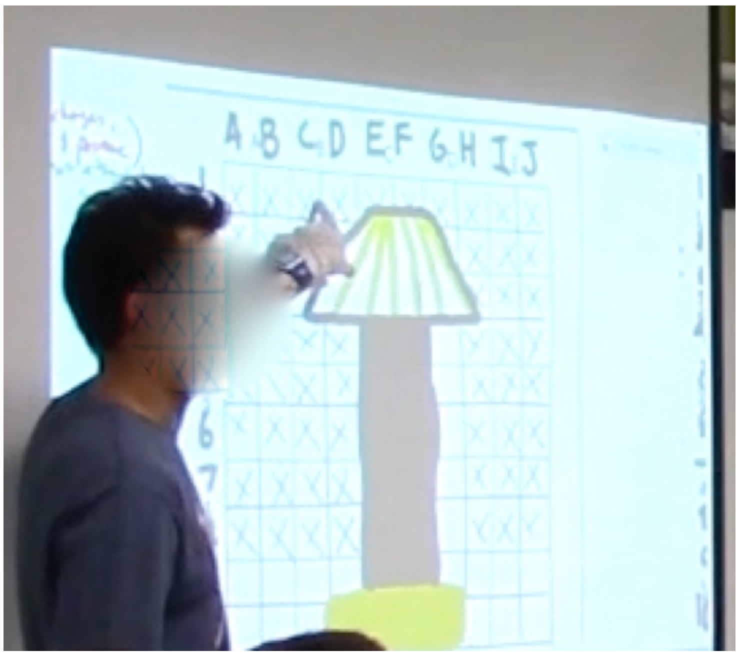
Figure 4.5: The Mystery Box



Picture taken from: https://learn.concord.org/interactions

Classroom observation. In the first interview that I had with Mark, he identified that he struggled to center students in his lessons. *"I want to show the class I am a strong facilitator they can depend on" "In my traditional teaching - when it was silent it meant… I needed to fill it. But now if I am supposed to build off their knowledge and I don't have a question already prepared, I feel like a fool"* (Interview 10.1.2015). Mark wanted to be a good teacher for his students, and felt that there had to be conversation going on at all times, and that centering students in discussion was difficult, and at times scary. "*I was sort of scared with the class discussions in period one because, what if I couldn't explain it? Or if someone asked a question I couldn't answer?"* Centering students in discussion became Mark's focal point for his own professional learning. This lesson begins with Mark doing the light box demonstration as prompted in the teacher materials. After the demonstration and data collection, the students answered two questions in the online portal 1) make a claim as to what was inside the box, and 2) to provide evidence for that claim. Students did this by drawing pictures inside the open grid marks in their graph paper as to what they thought was inside the box. Mark then guided the class in a large group discussion where he projected student data on the board for discussion as shown in Figure 4.6. This intent of this class discussion was to scaffold students in understanding how indirect evidence helped Rutherford draw conclusions about the structure of the atom, and to support student understanding constructing scientific explanations.

Figure 4.6: Mark Displaying Student Mystery Box Claim to the Class



Mark projected the student's answers and asked the class to analyze them. "So if we look at this student's answer, the said it's a remote control, how do we know it's a remote control?" ***"Because of the shape" "****Ok, but how do we know the shape?"* ***The laser didn't go through in those boxes so there is something there"*** *"That is what we need to see here, some evidence for the claim." "What does this student say? We used the laser that could go through the box and we marked the places where the laser goes through. Is that evidence?"* The class responds with **"Yes, uh-huh"** Mark did not respond, but instead read another student answer *"We used the* *laser to check what's in the box. We also drew empty boxes to guess what is inside the box."* ***"It doesn't say laser"*** *Well, I do see laser, but does it say the laser blocked?"* **"No, but it says does say laser…"** "Yeah, we aren't going to give him a hard time about that though." Mark read another student answer *"We used a laser to see if it can go through the box and we marked the places it went, what do you think?"* ***"It's half"*** *"Ok, what do you mean it's half?"* ***"It says where [the laser] went through but not where it didn't"*** *"Ok so this one would be half-credit?"* ***"Yes"*** As the discussion continued, students scrutinized answers even further to include grammar– which was not prompted by the teacher. Mark pulled up another response and read it out loud to the class *"When the laser goes through the box there's nothing blocking it, but when the laser is blocked there is something blocking it"* and a student replied ***"Well, there is a lot of repetition, but yes, it is evidence. [laughs]"*** (Observation 11.5.2015).

Classroom analysis. In this lesson, Mark integrated aspects of Framework element one; positions students as knowledge generators, and two features of project-based learning including 1) engaging students in collaborative activities, and 2) engaging students in scientific practices. Mark's instruction supported inclusive 3D instruction by allowing students to look at example answers and from data; students determined the criteria for "evidence". In doing so, Mark centered students in his class by allowing them to determine what good evidence included, positioning them as knowledge generators. He pushed them to explain their answers when they said "shape" was an important aspect of evidence and also when a student claimed that a student's response was "half-evidence". What Mark didn't say was just as important as what he did say in that refraining from evaluating student's responses as to which answer constituted good evidence pushed students to decide for themselves. Figure 4.7 includes examples of how Mark engaged with the first two sub-elements of "Positions students as knowledge generators".

Figure 4.7: Analysis of Mark's Classroom November 5th 2015

1.1 Positions students as knowledge generators

Clarification: During classroom discussion, the teacher does not evaluate ideas as correct or incorrect, but encourages students to provide evidence for ideas. Students evaluate each other's ideas using evidence and develop explanations through discussion.

1.1.1 Students generate ideas and evaluate ideas using evidence.

- In this lesson, the students determined that "shape" was an important piece of evidence, and that evidence had to contain discussion of *"laser going through"* and *"laser not going through"*
- Mark pushed students to explain their answers ***"****Ok, but how do we know the shape?"* and *"Ok, what do you mean it's half?"*
- Mark refrained from evaluating student's responses to whether or not an answer was considered evidence.

1.1.2 Students (as a community) develop explanations through discussion.

- Students weren't evaluating claims using evidence during this discussion, but they were building the skills necessary to do so by determining what constitutes good evidence.

1.1.3 Teacher consistently validates student's contributions, attributing ideas and knowledge to students, and using their ideas in discussion.

- I did not see evidence of Mark specifically validating individual student ideas during this lesson.

While I didn't see evidence of Mark validating specific student answers and bringing them up into discussion, this lesson may reflect a snapshot of his growing understanding of this Framework element. I find Mark's progress with positioning students as knowledge generators particularly significant as he discussed centering students as a major goal just one moth prior to this lesson. Also interestingly, although Mark allowed the students to make decisions about what does and doesn't constitute evidence, he also stepped into the discussion to set the "tone of the discussion". For example, when one student claimed the answer didn't include the term laser ***"It doesn't say laser"*** when the answer actually did have the word laser in it, but no information about what the laser is doing. Another student commented **"No, but it says does say laser…"** and Mark calmly responded with *"Yeah, we aren't going to give him a hard time about that though."*. In this way Mark was allowing students to make decisions about what does and doesn't constitute evidence, while also reinforcing the tone of classroom discussion to be professional and courteous. Lastly, Mark supported student understanding of constructing evidence based explanations – a scientific practice - by allowing students to develop and critique evidence as a group. The anonymous nature of the student answers was important for developing inclusive classrooms where all students feel comfortable sharing their ideas in class. This serves as evidence that positioning students at the center of knowledge can also support features of PBL including engaging students in collaboration and using scientific practices.

Comparing this lesson to the curricular materials (Appendix E), I notice that the discussion Mark had with students around the evidence for their mystery box claim was different than the example discussion provided in the teacher materials. The teacher materials suggest that students share their models in small groups first and to display a few in front of the class. Questions prompts for teachers include "Is there an object inside? How do we know? What can we tell about the object?" and "What is it made of?" However, Mark decided to engage students in a discussion around evidence, what constitutes evidence, and "how do we know what we know?" Mark's change to this discussion shaped student talk lesson in ways that positioned students as knowledge generators which directly addressed his specific goal of centering students.

Discussion

In this study, I examined classroom video of two urban high school science teachers to explore how inclusive three-dimensional instruction supported their implementation of a project-based science curriculum in ways that best meet the needs of their students. When Nathan and Mark made instructional decisions to best merge the curriculum with their teaching context, those decisions were aligned to both the inclusive 3D instruction supported during professional learning, and the features of project-based learning supported in the curriculum. For Nathan, getting students to ask questions and put their ideas into words was his goal and he used an online driving question board to elicit student knowledge. Nathan's online DBQ was a tool he developed to get students sharing ideas, but it also engaged students with technology and with a driving question. In Mark's classroom, students were used to a science classroom where the teacher told them the right answer to help them learn. Mark wanted to be a good teacher and his students to have faith in him as an educator, and centering students by allowing them to drive discussion was a challenge for him. However, in his classroom discussion concerning what constitutes evidence, he centered students in challenging them to determine "what is evidence". Mark positioned students as knowledge generators by allowing them to determine the criteria for good evidence. In doing so, he also promoted collaboration between students and engaged them in constructing evidence-based explanations – an important scientific practice. Engaging teachers in professional learning focused on inclusive instruction while they implemented an educative, project-based learning curriculum afforded them opportunities to integrate these two approaches. While the goals of eliciting student knowledge and centering students initially came from the teachers, these goals were supported by the educative teacher materials in Interactions and by the activities in the PLP. With this support, Nathan and Mark made curricular decisions that aligned with inclusive 3D learning, PBL, and met the individual needs of their context.

This work has important implications for various stakeholders including curriculum developers, professional development facilitators and policymakers. We know that both curricular materials and professional learning activities can influence the instructional decisions that teachers make (Jones & Tarr, 2007; Robitaille, & Travers, 1992), so having curriculum and PLPs that align with each other and allow teachers to make shifts to meet the needs of their context will be more successful. Curriculum developers should plan for teachers to make instructional decisions that best fit their needs and provide supports, such as educative materials, to promote the learning the goals of the curriculum while teachers implement it (Davis & Krajcik, 2005). Professional learning facilitators should likewise plan for contextual factors to influence how teachers ingrate ideas into their instruction. Since teachers are ultimately the experts of their context, including teachers in designing curriculum, and planning for implementation is crucial to their continued learning and success. Grounding PLPs in quality curriculum allows for the curriculum and instruction to support one another, which may better assist teachers in making the switch to NGSS. Additionally, policymakers will need a better understanding of what curriculum and professional learning in science will require so they can better enact policies that support quality programs financially, and promote teacher evaluation programs that reflect these important, new instructional approaches. Another important consideration for teacher evaluation is that both teachers were successful in implementing the curriculum and inclusive pedagogies – but the teaching that resulted looked very different for these two teachers. Flexible teacher evaluation protocols that allow teachers to make professional decisions that best support their individual classrooms are important.

Centering equity in curriculum and instruction is an important goal for education and a necessary avenue for educational research. Helping teachers develop inclusive science classrooms is only one step in promoting equitable science classrooms. Work moving forward should examine how the integration of inclusive 3D instruction and project-based curriculum supports student learning and the classroom environment. Examination of student work over time, interviews with students about how their learning is supported, and videos of classroom teaching could provide a more robust picture of how the classroom learning environment changes with this instructional approach. In an era of changing school demographics and a growing mistrust in science, it is imperative that we develop classrooms where all students feel safe to share and critique ideas, and have experiences generating science knowledge. Another research trajectory should examine how policies can impact teacher's ability to integrate inclusive science instruction with quality curricular materials. Standardized test reporting, teacher evaluation protocols, and even administrator's conceptions of what science learning looks like all have an impact on the science classroom, and these are all issues that must be addressed to build science classroom communities that are truly equitable.

APPENDICES

APPENDIX A: Interactions Unit One Summary

Unit 1: Why do some clothes stick together when they come out of the dryer?

Investigation 1: Why do some things stick together and other things don't?
In this investigation, students will begin to develop a conceptual model of electrostatic interactions by exploring how various charged objects (scotch tape, balloons, rods of various materials, and a Van de Graaff generator) interact with each other and with uncharged objects (paper, water bottle, a hand). By the end of the investigation, the student model will include positive and negative charges as well as patterns that can be used to explain and predict how charged objects interaction. *This investigation builds toward NGSS PE: HS-PS2-4*

HS-PS2-4. Use mathematical[13] representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects

Objective: Target Model
What should the student's conceptual model include?

- Objects can be positively charged, negatively charged, or uncharged (Neutral)
- Objects with the same charge repel each other, Oppositely charged objects attract each other. Charged and uncharged objects attract each other regardless of whether the charged object has a positive or negative charge.

Activities:
Activity 1.1 What are some examples of things that stick together and things that don't?
Activity 1.2 What are some patterns in how things stick together or push apart?
Activity 1.3 What effect do charged objects have on uncharged objects?
Activity 1.4 How do I know if something is positively or negatively charged?
Activity 1.5 How does an object's charge affect its interactions with neutral objects?

Investigation 2: What are factors that affect the interactions between objects?
In this investigation, students develop a model of electric fields to explain how charged objects interact. Students analyze how the charge on objects and the distance between them affects the strength of the interactions between those objects. *This investigation builds toward NGSS PEs: HS-PS2-4 and HS-PS3-5.*

HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects

HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

Objective: Target Model
What should the student's conceptual model include?

[13] Aspects of the performance expectation not addressed in this investigation are greyed out.

- Objects can be positively charged, negatively charged, or uncharged (neutral).
- Objects with the same charge repel each other; oppositely charged objects attract.
- The distance between charged objects affects the interactions between them. The closer they are, the stronger the interaction.
- The amount of charge on the charged objects affects the interactions between them. The greater the charge, the stronger the interaction.
- Charged objects generate an electric field in the region around them.
- It is through the electric field that charged objects interact with each other.

Activities:
Activity 2.1 How can charged objects have an effect on each other without touching?
Activity 2.2 How do factors like distance and amount of charge affect the interactions between objects?
Activity 2.3 How does our model of charge interactions connect with a variety of phenomena?

Investigation 3: What are all materials made of?
In this investigation, students will start by analyzing observations of matter in order to evaluate continuous and particle models of matter. Students will then use evidence from mixing water and ethanol to evaluate those models. Finally, students will apply their model to explain observations of gases. *This investigation builds towards NGSS PE: HS-PS1-3*

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Objective: Target Model
What should the student's conceptual model include?
- All substances are made of particles that are too small to be seen
- There is empty space between the particles making up substances.

Activities:
Activity 3.1 Can the same piece of paper be cut into pieces indefinitely?
Activity 3.2 Does 5 + 5 always equal 10?
Activity 3.3 Is the particle model always better?
Activity 3.4 Which model best supports our observations?

Investigation 4: What are nature's building blocks?
This investigation follows the historical development of models of atomic structure and provides students with the opportunity to explore simulations of some of the experiments that led to these models. In addition, through hands-on activities involving representative objects, this investigation helps students gain insight into the size of atoms as compared with other small objects. *This investigation builds toward NGSS PEs: HS-PS1-1 and HS-PS1-3*

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Objective: Target Model
What should the student's conceptual model include?

- All materials are made of particles that are too small to be seen.
- These particles are called atoms.
- Atoms have a dense, positively charged nucleus that consists of neutrons and protons; the nucleus is surrounded by much smaller, negatively charged electrons.
- Electrons can be modeled as a "cloud" surrounding the nucleus and are best represented in terms of probability maps.

Activities:
Activity 4.1 What are the particles that make up all substances and how small are they?
Activity 4.2 If you can't see it, how do you know it's there?
Activity 4.3 How do we know what's inside an atom?
Activity 4.4 Where are the electrons?

Investigation 5: How does an object become charged?
By collecting evidence as to how the composition of an atom relates to its identity, students will build upon the model of atomic structure that they developed in the previous investigation. In addition, they will explore the forces involved in maintaining an atom's structure and the effect that introduction into an electric field has on electron distribution. Students will extend their conceptual model of electrostatic interactions to include 1) electron transfer as the mechanism for how an object becomes charged and 2) shifting electron distribution to explain how neutral objects can be attracted to both positively and negatively charged objects. Finally, students will revise their models of some phenomena developed during previous investigations. *This investigation builds toward NGSS PEs: HS-PS1-1 and HS-PS1-3*

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Objective: Target Model
What should the student's conceptual model include?
Students' models of the structure of matter should include:

- All materials are made of particles called atoms which are too small to be seen with the unaided eye.
- Atoms have a dense, positively charged nucleus that consists of neutrons and protons surrounded by much smaller, negatively charged electrons. The nucleus takes up only a small fraction of the volume of an atom.
- Every element consists of a different type of atom; the identity of an element is determined by the number of protons in the nucleus of an atom of that element.

- An atom has an electric charge when it contains an unequal number or protons and electrons.

Students' models of electrostatic interactions should include:

- Opposite charges attract; like charges repel.
- The strength of the interaction between charged objects depends on the distance between them and the amount of charge on each object (qualitative understanding of Coulomb's law).
- Neutral objects are attracted to both positively and negatively charged objects.
- There is more than one way to charge an object.
    - An object can be rubbed with another material
    - Charge can be transferred to or from an object when it touches another object.
- Charge is due to electrons from atoms of one object transferring to atoms of another object.

Activities:

Activity 5.1 What is the effect of changing the composition of an atom?
Activity 5.2 How do objects become charged?
Activity 5.3 What causes neutral objects and charged objects to interact with each other?
Activity 5.4 Revisiting our models of charge interactions.

APPENDIX B: EQuIP Analysis of Unit One, Investigations One - Five

Table A1: EQuIP Analysis of Unit One, Investigations One

INVESTIGATION 1	Specific evidence from materials and reviewers' reasoning	Comments
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.		
i.Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.	**Asking Questions:** (A1) ● *Asking questions about why some things stick together and other things don't. "Discuss the nature of science, introduce the question 'Why do some clothes stick together when they come out of the dryer', and add it to the class driving question board." (Activity 1, TG[14] p. 8)* ● *"What questions do you have about clothes sticking together and hair standing on end?' (Activity 1, SM, p. 10)* **Developing and Using Models:** (A3,5) ● *"You will create your own model to explain your observations of the T and B pieces of tape, and the interactions between the water bottle and the paper or your hand. As you develop your models, be sure to think of the three aspects of modeling: Components, Relationships, Connection to the Phenomena" (Activity 3, SM p. 50).* ● *"Students will further develop a conceptual model of electrostatic interactions by generalizing the patterns of interactions between charged and neutral objects" (Activity 5, TG p. 69).* **Planning and Carrying out Investigations:** (A2,4) ● *Students carry out investigations using pieces of tape and magnets to observe how they interact: "Use the magnets to test your tape to see if the tape behaves like a magnet. Can you get the magnet and the tape to interact in all the same ways as the two pieces of tape?" (Activity 2, SM p. 29).* ● *Students carry out investigations by observed interactions between a water bottle and pieces of*	In this investigation, teachers are scaffolding students understanding of the scientific practices by hitting certain aspects of them to build understanding. For example: early in the investigation, students carry out investigations and later move to a place where they are planning their own investigation. All four practices are addressed evenly and explicitly in the unit, and scaffolds are put in place so

[14] TG = Teacher Guide, CR = Class Reading, SM = Student Materials Page number are directly from the teacher guide document (including student portions) or the associated reading documents.

Table A.1 (cont'd)

	paper when charged and uncharged. "Have one partner hold the empty plastic bottle by its cap, rub the bottle with an alcohol wipe, and let the bottle dry. Still holding the bottle by its cap, bring the bottle above and very close to the bits of paper, but don't touch them with the bottle" (Activity 3, SM p. 43). **Analyzing and Interpreting Data:** (A3,4) ● *After students complete a table based on their observations from the investigation with the water bottle, they are asked to interpret their data. "What do you think would happen if you brought your hand close to the small pieces of paper you used previously? Explain why" (Activity 3, SM p. 48).* ● *After students have designed their own investigation, and completed a table, they answer questions about their observations. "Based on your observations, make a claim about the charge of the T strip of tape" (Activity 4, SM p. 66).*	that teachers can help students build understanding.
ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.	**Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms (A1-3) ● *Students compare the patterns observed in the simulation to the patterns observed in the charged pieces of tape and identify that same charges move apart while opposite charges attract. "The charged objects in the simulation attracted when they had different charges and repelled when they were of the same charge. This is the same patterns as observed with the top and bottom tape" (Activity 2, TG p. 31).* **Types of Interactions:** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties and transformations of matter, as well as the contact forces between material objects (A3-5) ● *Sample student answers explaining their observations of the water bottle interactions: "The neutral object and charged object will be attracted to each other. My neutral hand and the neutral pieces of paper were both attracted to the charged bottle" (Activity 3, TG p. 48).*	This investigation is a precursor to later investigations where students explore these elements of the DCIs more in depth. This Investigation provides an excellent foundation for them to be able to meet each element later in the unit.
iii.Provides opportunities to develop and use specific elements of	**Cause and Effect:** (A1) ● *Students explore scenarios with cause and effect relationships to ask scientific questions and develop models: "If a person fell out of an airplane without*	While students do not directly focus on cause and effect

Table A.1 (cont'd)

the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.	*a parachute, that person would not survive because he or she would hit the ground with too much speed. However, if a parachute is used, the person falls more slowly and hits the ground at a safe speed" (Scientific Models, CR p. 1).* **Patterns:** (A2-5) ● *Students identify patterns in their observations of how pieces of tape interact: "Use the simulation to identify patterns in how charged objects interact. Think about how these patterns relate to the patterns you observed with the tape." (Activity 2, SM p. 29).* ● *Students identify patterns in their data to help them develop a new investigation. "Using your results from the table, develop a procedure to collect the evidence you need to determine the charge of the T and B tape strips" (Activity 4, SM p. 64).*	relationships, this investigation provides exposure to this CCC so that students can build this practice later. The investigation focuses much more heavily on patterns and students address this CCC throughout the investigation with detailed support.
iv.The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	● *Here, students explore the patterns in how some things stick together or push apart by identifying patterns in how charged pieces of tape interact. They further explore this phenomenon by using a computer simulation to identify patterns in two spheres in which charge can be manipulated. "Students will use **charged pieces of tape** and a **computer simulation** representing the interactions between charged spheres to **identify patterns** in how **electrically charged objects interact with each other**" (Activity 2, TG p. 23).* ● *Students carry out an investigation to explore the phenomena of attraction between a charged water bottle and uncharged pieces of paper. They will use the patterns they identified in previous activities to develop a model of electrostatic interactions. "Students will design and carry out an investigation to determine the charge of an object using an object of known charge as reference and their model of electrostatic interactions" (Activity 4, TG p. 56).* ●	Although students may not address every aspect of practices as discussed above, they are being scaffolding into their understanding of planning and carrying out investigations by first carrying them out and collecting data, and moving to planning later.
B. Lesson fit together coherently targeting a set of performance expectations		
i.Each lesson links to previous lessons and	Activities within this investigation are linked by the Driving Question "Why do some things stick together and other	Investigation does an

Table A.1 (cont'd)

provides a need to engage in the current lesson.	things don't?". Each activity has it's own Driving question that builds toward this overall theme. Examples below describe how these connections are made explicit to teachers and students. Each activity is linked to the previous one with a description of how the two are connected. ● *"In the last activity, students analyzed interactions between charged objects. In this activity, students will learn that most objects are inherently neutral and they will analyze interactions between neutral and charged objects" (Activity 3, TG p. 37).* Often this connection is also made explicit to students in the activities. ● *"For example, in a previous activity you observed how charged strips of tape attracted or repelled each other. How could you have determined which of the pieces of tape were positively or negatively charged?" (Activity 4, SM p. 60).*	excellent job of anchoring the materials with the overarching driving question, and making the connections between activities - and to the overarching goal - explicit to teachers and students.
ii. The lessons help students develop proficiency on a targeted set of performance expectations.	**HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.** ● *"By the end of investigation one, the model will include positive and negative charges as well as patterns that can be used to explain and predict how charged objects interact with each other and neutral objects attract each other. In later investigations, students will build upon their models of electrostatic interactions by incorporating electric fields and a qualitative view of Coulomb's law." (Introduction, TG p. 2).*	This investigation is a good introduction to Coulomb's Law and interactions between charged objects. However, students are not expressing their ideas in mathematical relationships at this time, and the curriculum never explores gravity.

Alignment Summary of Investigation One:

In this investigation, students engage in three-dimensional learning to answer the overarching question "Why do some things stick together and other things don't". The investigation begins with students exploring the scientific practices by carrying out investigations, and move to planning their own investigations later in this section. Similarly, the first activity doesn't explicitly have students exploring cause and effect relationships, but rather uses them as context in which students ask questions. This seems reasonable for the first investigation where students are building their understanding of practices and crosscutting concepts, and it will be interesting to see how these skills develop throughout the curriculum. This investigation does an excellent job of setting the foundation for the elements of DCIs it claims to address. It is worth noting that the curricular materials state up front that the intent is not to discuss gravity or have students express themselves in mathematical relationships, but rather focuses on developing a conceptual understanding of Coulomb's law and electrostatic interactions. Coherence is well represented in this investigation by anchoring student work with the overall driving question, and repeatedly making connections between activities clear to both students and teachers throughout the investigation.

Table A.2: EQuIP Analysis of Unit One, Investigation Two

<table>
<tr><td>INVESTIGATION 2</td><td>Specific evidence from materials and reviewers' reasoning</td><td>Comments</td></tr>
<tr><td colspan="3">A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.</td></tr>
<tr><td>i.Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.</td><td>Developing and Using Models: (A2,3)
● "Draw a model to represent the pattern of how the pointer interacts with the Van De Graaff generator as it is moved around to different sides of the generator. How does your model explain your observations?" (Activity 1, SM p. 12).
● [A model of the Franklin's Bells apparatus is provided for students] "What can you conclude about the relative amount of positive charge on object A and object B? Provide evidence to support your claim" (Activity 3, SM p. 44).
Analyzing and Interpreting Data: (1,2)
Students collect observational data during a demonstration and develop a model to explain their observations.
● "Draw a model to represent the pattern of how the pointer interacts with the Van De Graaff generator as it is moved around to different sides of the generator. How does your model explain your observations?" (Activity 1, SM p. 12).
● "What pattern did you observe when the tape what at different distances from the Van de Graaff machine?" (Activity 2, SM p. 25).</td><td>In activity one, modeling is highlighted much more explicitly than analyzing and interpreting data, although students engage in both practices. Activities two and three ask students to use simulations and demonstrations as models to draw comparisons of how charges interact in different situations. The practice of modeling is widely used in this investigation.</td></tr>
<tr><td>ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.</td><td>Types of Interactions: Forces at a distance are explained by fields (gravitational, electrical and magnetic) permeating space that can transfer energy through space. (A1-3).
● In activity one, students first observe that forces interact at a distance during a demonstration. "Watch as your teacher demonstrates with a metal triangle, moving it around all sides of the Van De Graaff generator (Activity 1, SM p. 12).</td><td>In this investigation, students explore how the distance between objects affects the strength of forces and make</td></tr>
</table>

Table A.2 (cont'd)

	Types of Interactions: Newton's Law of Gravitation and Coulomb's Law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (A2) ● "Review the experimental setup and have students observe what happens to the tape at different distances from the Van de Graaff generator. Ask students to summarize the relationship between distance and the strength of the force" (Activity 2, TM p. 26).	predictions based on their knowledge. Both elements of the DCI are captured in this investigation.
iii.Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.	**Cause and Effect:** (A2,3) In activity two, students are examining the cause and effect relationship between strength of forces and the distance between objects. ● "When the distance between the two objects changes, what do you notice about the strength of the electric force between the two objects?" (Activity 2, SM p. 30). **Structure and Function:** (A1) In this activity, students are collecting data to define the structure of an electric field so that later they can make the connection between the structure of a field and its function (strength of force due to distance, etc. ● "Use the "Trace force pointers" checkbox to track the pattern of forces around the object." (Activity 1, SM p. 14).	I do not see a good example of structure and function as a cross-cutting concept in this investigation, rather patterns are much more explicitly addressed here. Students begin by identifying patterns and move to identifying and predicting based on cause and effect relationships.
iv.The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	In activity one, students observe patterns of a metal pointer interacting with the Van De Graaff generator and draw a model. Later, students use these observations to draw conclusions about the sub-microscopic interactions. ● "**Draw a model** to represent **the pattern** of **how the pointer interacts with the Van De Graaff generator** as its moved around to different sides of the generator" (Activity 1, SM p. 12). In activity two, students use a simulation as a model to explore cause and effect relationships. ● "When the distance between the **two objects changes, what do you notice** about the **strength of the electric force between the two objects?** Be sure to describe what you **observe in the simulation** to support your answer. " (Activity 2, SM p. 30).	While activity one is three-dimensionally aligned.. It is not aligned to the dimensions described in the materials which could be confusing for teachers. However, evidence of three dimensional alignment

Table A.2 (cont'd)

		exists throughout the investigation.
B. Lesson fit together coherently targeting a set of performance expectations		
i.Each lesson links to previous lessons and provides a need to engage in the current lesson.	Each activity links to previous activities with a description of how they are related. ● "In the last investigation, students observed charged objects interacting without touching. To help students understand how electrically charged objects can interact through space, this activity introduces the concept of the electric field." (Activity 1, TG p. 7) ● "In the previous investigation, you developed some principles that you can use to help explain and predict how two charged objects will interact with each other. As you observed, attraction and repulsion can occur without the objects touching. How can that be?" (Activity 1, SM p. 11) Lessons also link back to the overarching driving question for the unit and allows students to continually build understanding towards this question. ● "Return to the DQ board and the unit-level driving question: Why do some clothes stick together when they come out of the dryer?" (Activity 3, TM p. 51).	This investigation does a great job of linking activities, and also linking back to the overarching driving question for the unit. This connection is made explicitly for students and teachers in both materials.
ii. The lessons help students develop proficiency on a targeted set of performance expectations.	**HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.** In activity two, students are using mathematical relationships in the form of directly and inversely proportional ● "When the charge on one object is increased (either positive or negative), what happens to the force on both objects?" (Activity 2, SM p. 30). **HS-PS3-5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.** ● "Draw a model to represent the pattern of how the pointer interacts with the Van De Graaff generator as its moved around to different sides of the generator" (Activity 1, SM p. 12). ● [A model of the Franklin's Bells apparatus is	Both performance expectations are addressed here, and there is even evidence of exploring qualitative mathematical relationships even though the curriculum claims to not address mathematical thinking as a practice. These PE's build nicely from

Table A.2 (cont'd)

	provided for students] "What can you conclude about the relative amount of positive charge on object A and object B? Provide evidence to support your claim" (Activity 3, SM p. 44).	those highlighted in the first investigation to build to the Unit's Driving question.

Alignment Summary of Investigation Two:

While there is evidence that activity one is three-dimensionally aligned, it is not aligned to the three dimensions labeled for teachers (in activity one). This could be confusing for teachers who are starting to learn about the three dimensions and the teacher materials should be amended to reflect this change. However, if activity one *claimed* to focus on models and patterns, I see a lot of evidence for three-dimensional alignment. Investigation two is also very explicit for students and teachers that the content reaches across activities and investigations to reach the overarching DQ for the unit. In addition, the curriculum goes further than intended in giving students opportunities to qualitatively address mathematical thinking by looking at cause and effect relationships as directly or inversely proportional.

Table A.3: EQuIP Analysis of Unit One, Investigation Three

INVESTIGATION 3	Specific evidence from materials and reviewers' reasoning	Comments
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.		
i.Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.	**Asking Questions:** (A1) The curriculum states that questions are provided for students to elicit ideas in this first activity (Activity 1, TG p. 10). ● "If the piece of paper is cut in half over and over again, will there ever be a point at which it is no longer paper? Explain your answer" (Activity 1, SM p. 9). **Developing and Using Models:** (A3) Students draw and revise models throughout this investigation, but modeling is highlighted more prominently in activity 3. ● "Draw a model of what you think air would look like if you could zoom in its structure and composition, just like you did for the liquids." (Activity 3, SM p. 35). **Engaging in an argument from evidence:** (A4) In activity 4, students make a claim as to whether the particle or continuous model fits their observations and provides evidence for their argument. ● "Provide two examples of observations from the activities in this investigation to use as evidence to support your argument. Explain why these observations support your choice for a particle or continuous model of matter." (Activity 4, SM p. 46). **Obtaining, evaluating and communicating information:** (A2) In activity 2, students communicate the information learned during the lesson by developing and explaining models, and constructing explanations. ● "Use your observations of the simulation to explain why mixing ethanol and water results in a measured, combined volume that is less than the sum of the original volumes." (Activity 2, SM p. 27).	While each activity in this investigation does a good job at integrating a practice, there is still evidence of scaffolding practices for students (providing questions for students to model asking questions) at this early stage of the curriculum, it makes sense, but if there were a practice that didn't need to much scaffolding, it would be asking questions. I wonder if this could be rewritten to have students asking questions.
ii. Provides opportunities to develop	**Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by	This investigation

Table A.3 (cont'd)

and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.	electrical forces within and between atoms. (A1) Students are working toward this DCI element by exploring the continuous and particle models of matter, and comparing those to their observations of interactions at the macro scale. **Structure and Properties of Matter:** Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. (A2-4) In activity 3, student measure the mass of air, even though it cannot be seen. ● "How did the mass of the open syringe compare to the mass of the closed syringe?" (Activity 3, SM p. 36). ● "Make a claim that answers the question Is gas matter?" (Activity 3, SM p. 37). ● "Return to your ideas about what would happen if you cut a piece of paper in half over and over again. Do you still agree with your original claim? What changes would you make to your original ideas and what evidence and reasoning caused you to change your thinking?" (Activity 4, SM p. 47).	does an excellent job of setting up the second element of structures and properties of matter, that matter is made of particles too small to be seen and has mass. The first element is really only hinted at in activity one as students won't get into the electrical forces until later investigations.
iii.Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.	**Patterns:** (A2) In activity 2, students are looking for patterns in the data to determine how mixing water/ethanol is different than mixing water/water. ● "What patterns do you see in the class data regarding observations of mixing water + water, ethanol + ethanol, and water + ethanol?" (Activity 2, SM p. 25). **Scale, proportion and quantity:** (A3,4) Students are exploring how the structure of atoms affects their observations of materials like liquids and gases at the macro level. ● "Draw a model of the air in the syringe that explains why the mass of the syringe when the stopper was closed differed from the mass when the stopper was open." (Activity 3, SM p. 38). **Structure and Function:** (A1) In activity one, students use "cutting a piece of paper" as a thought experiment to uncover whether the continuous or particle model of matter is consistent with their observations. ● "Show a summary of student responses using the teacher report. Use these as jumping off points to get students to clarify their understanding of the particle and continuous models of matter"	The crosscutting concepts are explicit here and there is evidence of them in each activity. While only one is listed per activity, elements of CC's string throughout the investigation (scale, proportion and quantity specifically).

Table A.3 (cont'd)

	(Activity 1 TG p. 15).	
iv.The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	"In this activity, students will record several observations of gases to inform **their questions** about **whether gas is matter (has mass and takes up space)** and how it **behaves when students manipulate a syringe.** Students will **apply the particle model** to explain those observations." (Activity 3, TG p. 30). "Students will **use evidence obtained** in this investigation **to support the theory that matter is made of particles too small to be seen**"	Evidence of the three-dimensions working together is found throughout the investigation.
B. Lesson fit together coherently targeting a set of performance expectations		
i.Each lesson links to previous lessons and provides a need to engage in the current lesson.	Teacher materials prompts the teacher to remind students what they do know, what they need to know and where they are going next. • "Remind students that they have not answered how objects get charged or why neutral objects are attracted to both positive and negative objects. In order to answer these questions, they need to learn more about what these objects are made of" (Activity 1, TG p. 5). • "So far in this investigation students have been asked to evaluate the particle model through their observations of liquids. Students will now be asked to evaluate if the particle model adequately explains phenomena involving gases." (Activity 3 TG p. 31).	One thing this curriculum seems to do very well in overall is coherence. Both the teacher and the student is constantly reminded of how each activity and investigation fits into the overall driving question for the unit.
ii. The lessons help students develop proficiency on a targeted set of performance expectations.	**HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.** Students are working toward the structure of matter at the microscopic scale and using that to explain observations at the macro scale. • "Revisit your initial model of a gas. Do the components of your initial model explain your observations of gas being compressed in the	While students aren't planning investigations, they are comparing their observations of matter at the bulk scale to the

Table A.3 (cont'd)

	syringe? If not, what revisions would you make to your model?" (Activity 3, SM p. 42).	microscopic properties of matter, which will later build to the electrical interactions.

Alignment Summary of Investigation Three:

Investigation three is very strongly three-dimensionally aligned. The only few items that I question are whether or not the practice of questioning needs to be scaffolded at this stage, or if the activity could be re-written to have students asking questions. One of the DCI elements seems to only be tangentially addressed by activity one as stated, but I was very happy to see that the cross-cutting concepts are very strong in this investigation, and as usual coherence is another strong point of the curriculum. It is easy to find evidence of the students engaging in the three-dimensions and making sense of the PE.

Table A.4: EQuIP Analysis of Unit One, Investigation Four

INVESTIGATION 4	Specific evidence from materials and reviewers' reasoning	Comments
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.		
i.Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.	**Developing and using models:** (A2-4) ● "Revisit your previous model of the atom, which you drew in activity 4.1. If your model has not changed, what evidence supports your original idea? If your model has changed, what evidence convinced you that you needed to change it? (Activity 2, SM p. 37). ● "What is inaccurate about the way atomic structure is represented in this model?" (Activity 4, SM p. 67) **Analyzing and interpreting data:** (A2) After doing an activity to explore how we can investigate things we cannot see, students analyze their data and look for patterns. ● "Based on the evidence your class collected, draw a picture on the grid to illustrate the size and shape of the object in the mystery box" (Activity 2, SM p. 27). **Obtaining, evaluating and communicating information:** (A1) Students communicate information in multiple ways during this activity including modeling, and constructing explanations. ● "Draw what you think an atom looks like. Make sure to label your model so that anyone can understand it. How does your model explain your observations of substances?" (Activity 1, SM p. 11).	Evidence of students using scientific practices are found throughout the investigation.
ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems.	**Structure and Properties of Matter:** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (A2-4) ● "Thompson believed that cathode rays were made up of tiny particles. Based on the simulation, what charge did these particles have?" (Activity 2, SM p. 30) **Structure and Properties of Matter:** The periodic table orders elements horizontally by the number of protons in	While activity one builds toward elements of the DCI, none are addressed explicitly. This activity is more focused on helping students

Table A.4 (cont'd)

	the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (A1) ● In this investigation, students examine the particles that make up an atom, explore their charges and collect evidence for how these particles interact within and between atoms. **Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (A1) ● Students work toward this DCI by defining an atom and estimating its size in activity 1. **Structure and Properties of Matter:** Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. (A2) ● "Thompson believed that cathode rays were made up of tiny particles. Based on the simulation, what charge did these particles have?" (Activity 2, SM p. 30)	envision how small an atom is than how it interacts with other objects.
iii.Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.	**Patterns:** (A2-4) After doing an activity to explore how we can investigate things we cannot see, students analyze their data and look for patterns. ● "Based on the evidence your class collected, draw a picture on the grid to illustrate the size and shape of the object in the mystery box" (Activity 2, SM p. 27). **Scale, proportion and quantity:** (A1) Students are exploring the relative size of atoms to items that they are familiar with. ● "Eight pennies can be lined up across a dollar bill. What would happen if we made a similar measurement with atoms?" (Activity 1, SM p. 14).	Crosscutting concepts seem to be more explicitly addressed in activities one and two, with three and four being less explicit about the use of patterns. The curriculum seems to assume students know that they are looking for patterns as they analyze data.
iv.The three dimensions work together to support students to	In activity 2, students are **analyzing patterns** in **evidence collected during a simulation** to draw **conclusions about charged particles.**	Given that the DCI's are only implicitly

Table A.4 (cont'd)

make sense of phenomena and/or to design solutions to problems.	• "Charge the plates so that the electric field between them is strong enough to deflect positive or negative atoms. How does the mass of an atom affect the amount a charged atom gets deflected?" (Activity 2, SM p. 33) In activity 3, students are pulling together the **data they analyzed** by **identifying patterns** and **drawing a model** to **explain Rutherford's work**. • "Draw a model of the atom that could explain rutherford's observations. Keep in mind, models must account for all evidence, so your model should still account for Thompson's observations.	addressed in this investigation, the three dimensions do work together in each activity.
B. Lesson fit together coherently targeting a set of performance expectations		
i.Each lesson links to previous lessons and provides a need to engage in the current lesson.	Both the teacher and student materials refer back to previous investigations and activities, and the driving question of the overall unit. • "Investigation 3 provided evidence that materials are made up of tiny particles. This activity defines those particles as atoms or molecules (groups of atoms)." (Activity 1, TG p. 7) • "In the last investigation, you found that the particle model of matter helps explain how materials behave." (Activity 1, SM p. 11).	The curriculum maintains high coherence with other investigations, activities and the unit driving question. Interactions continues to be strong in this category.
ii. The lessons help students develop proficiency on a targeted set of performance expectations.	**PE: HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** Students work toward this across the investigation by determining where the positive and negative charges are located in the atom. • "What do rutherford's results and the relationships shown in the simulation tell you about the positive charges inside an atom" (Activity 3, SM p. 52). • "Do you think it would be easier to change the number of protons or neutrons in a given atom? Why?" (Activity 4 TG, p. 66). **PE: HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances**	Information in this investigation works towards both PEs. Students must first understand the structure and organization of charges in an atom to get both of these PEs, my concern is that too much time

Table A.4 (cont'd)

	at the bulk scale to infer the strength of electrical forces between particles. ● "Recall that Rutherford observed that about 1 out of every 10,000 alpha particles bounded back. What does this tell you about the relative size of the small dense, positive nucleus compared to the size of the rest of the atom? (Activity 3, SM p. 56).	is spent determining that.

Alignment Summary of Investigation Four:

This investigation does a good job of addressing all of the practices and crosscutting concepts, and works toward elements of the DCI that are listed (although does not yet address them explicitly). A lot of time is spent using Rutherford and Thompson's experiment as a model and verifying their claims than is required in the standards, while trends of the periodic table seem missing. There is evidence of three-dimensional alignment in all activities and the curriculum maintains coherence with the rest of the investigations and units. Like the DCI, This investigation works toward understanding of the PEs in that students must have understanding of the inner structure of the atom and where charges are located to move forward with HS-PS1-1 and HS-PS1-3.

Table A.5: EQuIP Analysis of Unit One, Investigation Five

INVESTIGATION 5	Specific evidence from materials and reviewers' reasoning	Comments
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems.		
i.Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems.	**Developing and Using models:** (A3,4) Students use digital models and construct models by drawing in this investigation ● "Draw a model that explains why both positively and negatively charged pieces of tape stick to the wall (on the non-sticky side of the tape)." (Activity 3, SM p. 33). ● "Review your model of the pie pans and Van de Graaff generator from Investigation 1 and revise it by adding ideas that you have learned since then." (Activity 4, SM p. 39). **Analyzing and interpreting data:** (A2) ● "Review the data tables and look for a pattern in the charges of two objects after they were rubbed together. Describe the pattern." (Activity 2, SM p. 19). **Constructing explanations:** (A1) ● "Explain the evidence that supports your claim about what causes a neutral atom to get a charge." (Activity 1, SM p. 12). **Obtaining, evaluating and communicating information:** (A1) In activity one, students use a simulation to gather evidence about the structure and charges of atoms and use that evidence to develop claims and construct explanations. ● "Use the simulation to help you answer the following questions. Hint: When you are using the simulation, build a neutral atom first, then test various conditions to answer the question." (Activity 1, SM p. 10).	This investigation is very explicit about the practices used by students in each activity, and there is evidence of all four practices that are highlighted.
ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to	**Structure and Properties of Matter:** Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (A1-4) ● "In the last investigation, you learned that all materials are made of atoms, and analyzed evidence that atoms contain positively charged protons and negatively charged electrons. If an	All three DCI elements are explicitly covered in this investigation, and the activities give a nice wrap up

Table A.5 (cont'd)

problems.	object is neutral, what could you conclude about the charge of the atoms that make up that object?" (Activity 2, SM p. 20). **Structure and Properties of Matter:** The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (A1,2) ● "Explain what happens to an atom when the number of protons, neutrons, or electrons changes while the number of the other two particles remains the same." (Activity 1, SM p. 6). **Structure and Properties of Matter:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (A3,4) Example student responses show the content behind this" ● When negatively charged tape is used, the electrons of the atoms that make up the part of the wall nearest the tape shift away from the negatively charged tape providing greater exposure to the positive nucleus. The negatively charged tape and the positively charged part of the wall are attracted to each other." (Activity 3, TG p. 33).	to the work students have been doing to develop models of electrostatic interactions.
iii.Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems.	**Cause and Effect:** (A3,4) ● "Take a snapshot that shows what happens when a neutral atom interacts with a negatively charged object." (Activity 3, SM p. 31). ● "Create a series of drawings that provide a step-by-step explanation of how the Franklin's bells device works." (Activity 4, SM p. 43). **Structure and Function:** (A1,2) ● "Explain the evidence that supports your claim about what causes a neutral atom to get a charge." (Activity 1, SM p. 12).	The crosscutting concepts are in each activity, but cause and effect is more implicit than explicit. In fact, I find evidence that patterns is potentially a stronger crosscutting concept here, although cause and effect is addressed.
iv.The three dimensions work together to support students to make sense of	Three-dimensions work together in each activity and are explicit, although sometimes the dimensions are used that are not specified in the activity. ● "**Review the data tables and look for a pattern**	All activities have some evidence of students

Table A.5 (cont'd)

phenomena and/or to design solutions to problems.	**in the charges of two objects after they were rubbed together**. **Describe the pattern**." (Activity 2, SM p. 19). ● "Now lets return to the beginning of the unit. We started the unit by asking, **Why do some clothes stick together when they come out of the dryer**? **Write a complete scientific explanation** that **answers this question**." (Activity 4, SM p. 45)	engaging in the three dimensions, although sometimes not necessarily the dimensions listed in the lesson.
B. Lesson fit together coherently targeting a set of performance expectations		
i.Each lesson links to previous lessons and provides a need to engage in the current lesson.	This Investigation, like the others is strong in coherence for students and teachers. ● "In the last investigation, you learned that the particles that make up substances are either individual atoms or molecules. Incredibly, only slightly more than 100 types of atoms make up all substances." (Activity 1, SM p. 5). ● "In the previous activity, students learned that adding or removing electrons changes the charge of an atom. In this activity, as they further develop a mechanism for how things become charged, students will explore simple electrostatic phenomena from prior activities to construct a model that includes electron transfer and conservation of charge." (Activity 2, TG p. 13).	This curriculum is so excellent at linking the activities and investigations together within the larger unit. Connection are explicitly made for students and teachers in many locations.
ii. The lessons help students develop proficiency on a targeted set of performance expectations.	**PE: HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.** This investigation works towards this PE by having students explore the relationship between components and charges in atoms, but does not go so far as to have them make predictions based on the electrons in the outermost level. ● "In the last investigation, you learned that all materials are made of atoms, and analyzed evidence that atoms contain positively charged protons and negatively charged electrons. If an object is neutral, what could you conclude about the charge of the atoms that make up that object?" (Activity 2, SM p. 20).	Aspects of both PEs are addressed here fairly thoroughly. Students at this stage are not making predictions of element properties based on electrons in the outer shell, but are prepared to do that.

Table A.5 (cont'd)

	PE: HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. ● When negatively charged tape is used, the electrons of the atoms that make up the part of the wall nearest the tape shift away from the negatively charged tape providing greater exposure to the positive nucleus. The negatively charged tape and the positively charged part of the wall are attracted to each other." (Activity 3, TG p. 33). ● "Now lets return to the beginning of the unit. We started the unit by asking, Why do some clothes stick together when they come out of the dryer? Write a complete scientific explanation that answers this question." (Activity 4, SM p. 45)	

Alignment Summary of Investigation Five:

This was a good wrap up for unit one - engaging students in practices and crosscutting concepts while addressing the core ideas. Coherence is strong here, and the curriculum works to tie up loose ends for students so they can progress to unit two. The only criticism is that there doesn't seem to be a method for which dimensions to name as being addressed or not. Many practices are listed here (4) but only two crosscutting concepts are listed even though patterns is explicitly addressed.

APPENDIX C: Curriculum Analysis of Supports for Inclusive 3D Instruction

Table A.6: Analysis of Support for Inclusive 3D Instruction in Investigation One

INVESTIGATION 1	Specific evidence from materials and reviewers' reasoning	Comments
A. Developing an Inclusive Classroom: How well does the curriculum support teachers in developing a learning community that values ideas, cultural and linguistic differences? Does the curriculum support teachers and students in working as a community where everyone feels safe, supported and encouraged to express ideas?		
i. Positions students at the center of knowledge generation in the classroom.	**Sample student answers:** ● *"Students may also invent fantastical causes such as magic. Even though this may seem like a thoughtless answer from the student, if you treat it as a serious answer you are setting the tone in your class that you care about student's ideas and that all ideas are welcome and will be taken seriously;" (Activity 1, TG[15] p. 10).*	Investigation one sets-up the idea that student ideas are the most important thing in the classroom and even when those ideas seem "silly" they can be taken up in discussion and validated or dismissed using evidence. In this sample answer the idea that "all ideas are welcome and are taking seriously" is important for this aspect of developing an inclusive classroom.
ii. Encourages and provides tools to leverage and value student's funds-of-knowledge and ways of knowing	**Discussion prompts for teachers:** ● *"In order to get students to share ideas and engage in lively discussions, it is important to set a tone that all ideas are important" (Activity 1, TG p. 10).* ● *Questions to support building a classroom community: Does anyone have a different idea, Does anyone have a similar idea?, Do you agree or disagree with that idea?, What questions could we ask or investigate to sort out that idea?" (Activity 1, TG p. 10).* ● *"The goal of the discussion should be to get a variety of ideas from students, not to focus on "correct" ideas. See Appendix for additional suggestions and tips for leading discussions" (Activity 1, TG p. 14).*	Discussion prompts in investigation one reiterate that all ideas are important to develop an environment where students feel safe to speak up. Tolls are available in all discussion prompts to help teachers draw ideas out of students. However, there is no explicit goal of drawing out specific funds-of-knowledge that students bring the classroom, it is more implied in these statements.

[15] TG refers to the Interactions Teacher Guide.

Table A.6 (cont'd)

iii. Encourages teachers to allow use and sharing of student language to explore phenomena.	**Sample student answers:** ● *"Clarification: students do not need to use the technical terms (Attract, repel, etc.)" (Activity 2, TG p. 27).*	In this sample student answer, teachers are told that students do not need to use the scientific language. However, it is not explicit that students should be able to use their own language to understand ideas so they may later learn the scientific language.
iv. Provides opportunities for teachers to value student's lived experiences as evidence for explanation and argumentation.	**Discussion prompts for an in class reading:** ● *"What ideas from class or your life can you connect to the reading? (Activity 3, TG p. 50).* ● *"What are some additional examples of electrical interactions that you have experienced at home (Sparks when folding blankets etc)" (Activity 4, TG p. 59).* ● *"Why is it that sometimes we shock ourselves when we touch something metal? Have you ever shocked someone else?" (Activity 5, TG p. 72)*	Discussion prompts in investigation one do provide tools and opportunities for teachers to help students connect what they are learning to lived experiences. (also evidence toward Funds-of-knowledge) but it is not explicitly states that students can use these experiences as evidence in explanation and argumentation.
v. Provides opportunities for students to develop and use their critical lens to solve problems.	**Discussion Prompt: Teacher displays anonymous student models to the class** ● "Do you notice any similarities and differences in the models we drew? Which models are most useful for explaining how the different types of tape interacted?.. What additional questions could we ask or what additional evidence do we need to revise our models?" (Activity 3, TG p. 54).	Again, investigation does a nice job of setting up experience where students develop and use their critical lens to critique models. Although they are not solving problems at this stage, It makes sense that students would be working to develop this lens for later use.

Summary of Investigation One:

Investigation one does an excellent job of setting the tone that student ideas are important and provides strategies for teachers to help elicit those ideas - although it does not go as far to say that student ideas drive instruction (that is implied). Likewise, Investigation one provides a lot of support for teacher to access student ideas - but does not go as far to describe that student funds-of-knowledge are important to classroom engagement and knowledge building. The teacher materials do not explicitly state that students should be able to use their own language to make sense of phenomena, but does state that teachers should refrain from correcting students (implying that students could use their language rather than scientific language). The materials provide examples of prompts teachers could use to help students bring their lived experiences into discussion, although nothing specifically states that students be allowed to use those experiences in explanation and argumentation. Finally, there are many opportunities for students to develop and use their critical lens and it makes sense that students would be developing their critical lens and practicing it early in the curriculum, and move to solving problems later on.

Table A.7: Analysis of Support for Inclusive 3D Instruction in Investigation Two

INVESTIGATION 2	Specific evidence from materials and reviewers' reasoning	Comments
A. Developing an Inclusive Classroom: How well does the curriculum support teachers in developing a learning community that values ideas, cultural and linguistic differences? Does the curriculum support teachers and students in working as a community where everyone feels safe, supported and encouraged to express ideas?		
i. Positions students at the center of knowledge generation in the classroom. (learning is driven by student ideas)	**Discussion prompt for evaluating models:** ● "Note that students developed different and creative ways to represent the space around the Van de Graaff generator. It is important to emphasize that students are not "incorrect" for using different representations, but their representations need to have enough information to be easily understood" (Activity 1, SM p. 13). ● "This is a good point to push students to build on and add to each other's responses. Establishing that there are multiple acceptable responses helps build a classroom environment where students are comfortable sharing ideas" (Activity 2, TM p. 36).	The curriculum continues to center students and the classroom community at the center of knowledge generation by giving students opportunities to share ideas, evaluate each other's responses and reach consensus as a class. The curriculum here is strong with this one.
ii. Encourages and provides tools to leverage and value student's funds-of-knowledge and ways of knowing	**Discussion prompts - Possible questions:** ● "What patterns did you notice? What is being represented in the model? What does that communicate? How could you use this to explain what we observed with the Van De Graaff generator?" (Activity 1, TM p. 16).	The funds-of-knowledge accessed in the investigation seem to be increasingly funds developed in class. There is little support for teachers to access outside sources of knowledge from home or the community.
iii. Encourages teachers to allow use and sharing of student language to explore phenomena.	**Sample answers - Clarification:** ● "Students do not need to use the term electric field nor understand the development of electric field. Students should just connect pointers as a way to represent the space around the Van De Graaff" (Activity 1, TM p. 15).	While there isn't explicit support for teachers to allow use of student language, the curriculum does discourage requiring high level scientific language by students.
iv. Provides opportunities for teachers to value	**Student questions** ● "What can you conclude about the relative amount of positive charge on object A and	While students are being asked to provide evidence based on their

Table A.7 (cont'd)

student's lived experiences and include them as evidence for explanation and argumentation	object B? Provide evidence to support your claim" (Activity 3, SM p. 44).	classroom experiences, there are no supports or encouragement for teachers to include evidence from outside the classroom for explanation or argumentation. The curriculum tends to heavily value in class experiences.
v. Provides opportunities for students to develop and use their critical lens to solve problems.		I do not see evidence of students evaluating their work, or using their lens to solve problems. Only application of knowledge is present here.

Summary of Investigation Two:

Investigation two does an excellent job of positioning students at the center of knowledge generation, but only approaches the other four elements in this criteria. The funds-of-knowledge that are valued and leveraged tend to be funds-of-knowledge that are developed and shared in class and not from outside of school which can disadvantage ESL students or students who were absent during a particular investigation or activity. The curriculum also does not explicitly state that teachers should allow students to use the language they are comfortable with to explore phenomena, but rather puts "upper limits" on the terminology students should know at this point. Again, when requiring evidence for explanation and argumentation, evidence from class knowledge is what is valued and promoted. I did not see any evidence of students evaluating or critiquing their work to develop a critical lens, or to use that to solve problems - only application of knowledge to “solve a problem” is used. However, the problem, experiences, and knowledge are all provided from within class and doesn’t give the student any entry other than classroom based entry points.

Table A.8: Analysis of Support for Inclusive 3D Instruction in Investigation Three

INVESTIGATION 3	Specific evidence from materials and reviewers' reasoning	Comments
A. Developing an Inclusive Classroom: How well does the curriculum support teachers in developing a learning community that values ideas, cultural and linguistic differences? Does the curriculum support teachers and students in working as a community where everyone feels safe, supported and encouraged to express ideas?		
i. Positions students at the center of knowledge generation in the classroom. (learning is driven by student ideas)	• "Ask for clarification, but do not evaluate student's responses. Students will have the opportunity to collect evidence and evaluate their own ideas in later activities" (Inv 3 Summary, TG, p. 5). **Teacher Note:** • "Students might say that evaporation or drops left in the other graduated cylinder or on the stopper could account for the loss in volume when the ethanol and water were mixed. This is a good hypothesis that should be tested" (Activity 2, TG p. 25). **Discussion Prompt** • "Discuss and compare the different models. Ask students what changes they would make to the models in light of their new evidence and begin to develop a consensus about the nature of matter" (Activity 2, TG p. 29). • "Place a consensus model on the DQ board" (Activity 3, TG p. 43).	The curriculum continues to do a good job at positioning the students at the center of knowledge by having students share ideas, shape those ideas based on evidence, and work toward consensus in the classroom community.
ii. Encourages and provides tools to leverage and value student's funds-of-knowledge and ways of knowing	**Teacher Discussion Prompts:** • "Be sure to ask students to express their ideas, not just state which students they agree with. Possible questions: What do you think will happen to the paper? Does anyone have a similar idea? Does anyone have a different idea?" (Activity 1, TG p. 12).	While there are many prompts for teachers to leverage and value funds-of-knowledge from class, those supports don't extend to leverage funds that come from outside of the classroom.
iii. Encourages teachers to allow use and sharing of student language to explore phenomena.	**Teacher's Note:** • "In this investigation, try to avoid using terms such as atoms, molecules, atomic etc. so that students may share ideas beyond memorized responses" (Activity 1, TG p. 8).	There is very little support for helping teachers encourage use of student language other than to limit the level of vocabulary used. In this example,

Table A.8 (cont'd)

		words are avoided because of incorrect or incomplete background knowledge it might trigger from previous science classes.
iv. Provides opportunities for teachers to value student's lived experiences and include them as evidence for explanation and argumentation	**Student Question:** ● "Use your observations of the simulation to explain why mixing ethanol and water results in a measured, combined volume that is less than the sum of the original volumes." (Activity 2, SM p. 28). ● "Develop a complete scientific explanation to answer the following question: Is gas matter? Write your claim, evidence and reasoning below" (Activity 3, SM p. 37).	There are really specific scaffolds for teachers to help students construct explanations and arguments using evidence - with the caveat that all this evidence comes from class and there is no support for teachers to value outside of school experiences.
v. Provides opportunities for students to develop and use their critical lens to solve problems.	**Student Question:** ● "Here are some ideas that other students shared. As you read through them, compare these responses to your own and consider how they are similar or different" (Activity 1, SM p. 10). ● "Revisit your initial model of a gas. Do the components of your initial model explain your observations of gas being compressed in the syringe? If not, what revisions would you make to you model?" (Activity 3, SM p. 42). ● "Who would like to share their claim? Does anyone want to share an evidence answer that they are not sure about? The goal is not to have the right answer, but to use our answers to better understand how to write a scientific explanation" (Activity 4, TG p. 46).	There are many examples of students working to evaluate and critique their work and the work of their peers to develop a critical lens, but it is not necessarily used to solve a particular problem, rather to answer overarching questions.

Summary of Investigation Three:

Similarly to Investigation two, this investigation continually supports teachers in positioning students as generators of knowledge by eliciting ideas from students. However, there are no additional supports for teachers in eliciting and leveraging funds-of-knowledge or in valuing home or community based knowledge. There are few language supports which are focused around the upper limit of vocabulary that students should know at a given point, but no explicit valuing of student language in class. Student experiences seem limited to classroom experiences and there aren't really supports for teachers in accessing student experiences outside school for use in discussion. Finally, there are ample opportunities in this investigation for students to critique and evaluate their own work and work of their peers. I also noticed that the discussion on page 13 seems to be more lecture based and doesn't really seem to fit in with the pedagogical stance or format of the rest of the curriculum.

Table A.9: Analysis of Support for Inclusive 3D Instruction in Investigation Four

INVESTIGATION 4	Specific evidence from materials and reviewers' reasoning	Comments
A. Developing an Inclusive Classroom: How well does the curriculum support teachers in developing a learning community that values ideas, cultural and linguistic differences? Does the curriculum support teachers and students in working as a community where everyone feels safe, supported and encouraged to express ideas?		
i. Positions students at the center of knowledge generation in the classroom. (learning is driven by student ideas)	**Discussion Prompts:** ● "Start the discussion by reminding students of their conclusion from the last investigation" (Activity 1, TG p. 10). ● "Make sure students agree that it was reasonable for Rutherford to ignore the electrons, why this is reasonable, and set up the upcoming simulation." (Activity 3, TG p. 49).	In activity one, students are reminded of knowledge they previously generated in Activity 3 and reached consensus as a group. In this Investigation, students are given claims and uncover evidence to determine whether those claims are supported - then develop consensus as a class. The class seems to be confirming rather than generating knowledge.
ii. Encourages and provides tools to leverage and value student's funds-of-knowledge and ways of knowing	**Discussion Prompts:** ● "The goal of the discussion should just be to generate a variety of ideas, not to evaluate any of them at this point" (Activity 1, TG p. 11). ● "Have students share their papers. Students could all stick their paper up on the wall, or you could have several students volunteer to share theirs. Possible Questions: What patterns do you notice? What is similar across these papers?" (Activity 4, TG p. 69).	Teachers are encouraged to leverage students funds-of-knowledge, but those funds are explicitly drawn from class experiences and not other funds.
iii. Encourages teachers to allow use and sharing of student language to explore phenomena.		The curriculum seems to be shifting much more closely to language developed and agreed upon in class rather than allowing students to use other forms of language to describe phenomena.

Table A.9 (cont'd)

iv. Provides opportunities for teachers to value student's lived experiences and include them as evidence for explanation and argumentation	**Student Questions:** ● "How does the evidence from Thompson's experiments support the plum pudding model of the atom?" (Activity 2, SM p. 40). ● "Draw a model of the atom that could explain Rutherford's observations. Keep in mind, models must account for all evidence, so your model should still account for Thompson's observations" (Activity 3, SM p. 54).	This particular investigation has students reviewing claims made by Thompson and Rutherford, collecting evidence, and explaining whether or not the evidence collected supports those claims. There doesn't seem to be space for students to bring in any evidence other than what is done in class.
v. Provides opportunities for students to develop and use their critical lens to solve problems.	**Discussion Prompts:** ● "Have students share their initial models in small groups so that they can critique them and build on each other's models." (Activity 2, TG p. 28). ● "Review different student models. Note the variety of representation, and ask students what they think about the different models" (Activity 2, TG p. 38). **Student Questions:** ● "In what ways did Rutherford's experiment NOT support the plum pudding model?" (Activity 3, SM p. 54).	Students are encouraged to use evidence to back claims, but in this case the claims are supplied for them as are the methods of obtaining evidence. Students are verifying claims others have made rather than making their own. I think this Investigation could be modified to remove the historical significance and have students make these claims. Once the content is learned, the teacher could interject (This guy Thompson noticed that too). Similarly to how we organize other experiences with phenomena in this curriculum.

Summary of Investigation Four:

This investigation seems to be organized differently, and as such it does not to a good job of hitting any of the goals for developing an inclusive classroom. In this investigation, the claims (that others have made) are given to students as are the modes for obtaining evidence. Students use that evidence (no room to bring in other evidence) to Verify Thompson and Rutherford's claims and experiments. While students are encouraged to share those ideas, my sense is that they are largely being led to those ideas whereas in previous investigations, students had more autonomy to do so. I think this Investigation could be modified to remove the historical significance and have students make these claims. Once the content is learned, the teacher could interject (This guy Thompson noticed that too). All knowledge here feels like it comes from those who were here before, and evidence is developed and shared from class only.

Table A.10: Analysis of Support for Inclusive 3D Instruction in Investigation Five

<table>
<tr><th>INVESTIGATION 5</th><th>Specific evidence from materials and reviewers' reasoning</th><th>Comments</th></tr>
<tr><td colspan="3">A. Developing an Inclusive Classroom:
How well does the curriculum support teachers in developing a learning community that values ideas, cultural and linguistic differences? Does the curriculum support teachers and students in working as a community where everyone feels safe, supported and encouraged to express ideas?</td></tr>
<tr><td>i. Positions students at the center of knowledge generation in the classroom. (learning is driven by student ideas)</td><td>Student Responses:
"In addition to answering the question, the goal here is for students to realize that they need to explore the simulation systemically in order to discover the answers and then to recognize that this mean altering one parameter at a time. You may need to use talk moves with students to elicit this behavior." (Activity 1, TG p. 6).
Discussion Prompts:
"As a class, build a consensus about the patterns in the data." "Possible questions: Why do you think each pair always has one positively charged object and one negatively charged object? What might be happening to account for this observation?" (Activity 2, TG p. 22).
"Return to other class questions students posed throughout this unit, and see if their models can help them answer those questions" (Activity 3, TG p. 34).</td><td>Investigation five does a good job of asking teachers to support students in exploring evidence, evaluating ideas, and developing classroom consensus to generate knowledge. Students are positioned as the generators of knowledge here explicitly in multiple places.</td></tr>
<tr><td>ii. Encourages and provides tools to leverage and value student's funds-of-knowledge and ways of knowing</td><td>Student Responses:
[If materials became charged by transferring protons] "The atoms would become a different element. Ask students how that would play out in the material itself or in the real world" (Activity 1, TG p. 12).
"The goal in asking this question is to explore what students think. They are not expected to provide the correct answer at this point" (Activity 3, TG p. 29).
Discussion Prompt:
"Possible questions: What does it mean to say that an object is charged?" "What do you think is happening when two objects are rubbed together?" (Activity 2, TG p. 19).</td><td>Funds-of-knowledge are accessed and valued, but as the curriculum progresses the focus tends toward classroom developed funds-of-knowledge and no support is given for teachers to support funds outside of the classroom.</td></tr>
</table>

Table A.10 (cont'd)

iii. Encourages teachers to allow use and sharing of student language to explore phenomena.	**Discussion Prompts:** ● "Point to an atomic number (without telling students it is called an atomic number) and ask, what does this number tell you about the atoms of this element?" (Activity 1, TG p. 5).	This is basically missing from this investigation, other than to have prompts that limits the level of vocabulary used with students.
iv. Provides opportunities for teachers to value student's lived experiences and include them as evidence for explanation and argumentation	**Discussion Prompts:** ● "Remind students that they should use evidence to evaluate classmates' models" (Activity 2, TG p. 24). ● "Ask students to choose aspects of each model that they agree and disagree with using ideas, information and evidence explored in the unit" (Activity 4, TG p. 41).	Again, the lived experiences that are valued and leveraged include mostly classroom experiences with no support for teachers to bring other experiences into class and use them for evidence.
v. Provides opportunities for students to develop and use their critical lens to solve problems.	**Discussion Prompts:** ● "Remind students that they should use evidence to evaluate classmates' models" (Activity 2, TG p. 24). ● "In addition, select two students models and compare their initial models with their revised versions and their current models. Discuss how their models have changed" (Activity 4, TG p. 41).	Students are encouraged to develop a critical lens and to use evidence in their critique, however it is not then applied to solve problems, other than maybe issues that come up in class when developing class consensus.

Summary of Investigation Five:

Investigation five is a good summary of the unit and provides some scaffolds for teachers in developing an inclusive classroom. The curriculum does an excellent job at positioning the students at the center of knowledge generation here, and in classroom aspects of leveraging funds-of-knowledge, using evidence for argumentation, and developing a critical lens. The only element of developing an inclusive classroom that isn't here is allowing students to use their own language to explore concepts. Here, the curriculum only limits the level of vocabulary used rather than explicitly supports teachers in encouraging use of comfortable language. It is implied that classroom language developed through consensus is acceptable.

APPENDIX D: Teacher Material Excerpt for Unit One, Investigation Three, Activity Three

Figure A.2: Teacher Material Excerpt: U1, I3, A4

Activity 3.3 (Student materials): Is the particle model always better?

Introducing the Lesson

Review the Worksheet for Activity 3.2. Ask students to share which models they selected as being able to account for their observations of mixing water and ethanol. (Note: Students may select different models for different reasons.) The purpose of this discussion is to reinforce the idea that different models can be used to explain the same phenomena. Even though different models can be used to explain the same phenomena that does not mean that all models are acceptable. It is important to emphasize that models should be evaluated based on how well they account for observations of the phenomena. Be careful not to judge students' responses; instead, encourage students to share a variety of ideas.

Possible questions:

- *Which model do you think best depicts what happened when water and ethanol were mixed? How does the model account for your observations?*
- *Did anyone else pick a different model?*
- *I noticed no one has mentioned picking model ____. Did anyone pick that one? Why or why not?*

This activity asks students to apply the particle model to a new situation. Models are most useful when they can be used to explain and predict a variety of phenomena.

Possible questions:

- *Does the particle model apply to other states of matter? Be sure to ask students to explain their answers.*
- *If the particle model works for gases as well as liquids, what will that tell us about the model?*

Teacher Material Excerpt from: https://learn.concord.org/interactions

APPENDIX E: Teacher Material Excerpt for Unit One, Investigation Four, Activity Two

Figure A.3: Teacher Material Excerpt: U1, I4, A2

2. Explain what evidence you used when considering what to draw.

Student responses: The illustration is the student's "claim." Student explanations should include reference to the data generated by the laser pointer (evidence) and provide a rationale for how that leads them to a particular conclusion (reasoning).

- Something solid must be in the area where the light was blocked. There must be something plastic or glass in the area where the light was blurred.

Discussion

Have students share their initial models in small groups so that they can critique them and build on each other's models. Display or present some of the models at the front of class and discuss their similarities and differences. Ask students to defend their ideas, but do not evaluate their drawings. Rather, ask students to explain how their models are consistent with **all** the observations they have made so far. This is an opportunity to explore how the same data can sometimes be interpreted in different ways. This happens in science as well, especially when experiments push the boundaries of what is known.

Possible questions:

- *Is there an object inside?*
- *How do we know?*
- *What can we tell about the object?*
- *What is it made of? What is it not made of?*

Note: *****Be sure you do not tell students what is inside the box.***

Homework: Reading 1 for Activity 4.2

What If It Is Impossible to Directly Measure or Make Observations?

Teacher Material Excerpt from: https://learn.concord.org/interactions

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CHAPTER 5: DISCUSSION

Empowering teachers to develop inclusive three-dimensional (3D) science classrooms where students are valued and feel safe to share and critique ideas can serve as a stepping-stone to promoting equitable science classrooms. To this end, I first developed and validated *The Framework for Inclusive Three-dimensional Science Classrooms*, and clarified framework features by providing examples from two veteran science teachers in various parts of the country. Next, I used *The Framework for Inclusive Three-dimensional Classrooms* as a guiding pedagogy for a professional learning program (PLP) that I designed for teachers. The program was developed using research in effective teacher learning programs, and was grounded in a 3D science curriculum called Interactions. I examined how teachers engaged with the PLP and put their learning into practice. Findings indicated that each teacher accessed different aspects of the PLP and implemented their learning in different ways. Although each teachers' classroom instruction looked different, they integrated inclusive 3D instruction in ways that met the needs of their students. Finally, I focused in on the classroom instruction of two teachers to examine inclusive 3D instruction supported teachers in implementation of Project-based Learning (PBL) to best support the needs of their students. My analysis yielded two rich examples of teachers integrating framework elements from *The Framework for Inclusive Three-dimensional Science Classrooms* with the features of PBL presented in the curriculum. In addition, each teacher combined inclusive, 3D instruction with PBL in ways that supported their individual classroom needs – for Nathan it was eliciting ideas, and for Mark it was centering students. Ultimately, engaging teachers in a PLP focused on inclusive instruction while they implemented a project-based curriculum afforded them opportunities to support student learning by integrating these two approaches.

While discussion of limitations are embedded within each study, there are limitations that span all three studies worth highlighting. First, I acknowledge that this dissertation study focuses on only four urban high school science teachers – a small number of participants. Hopefully, scale of this type of PLP will allow for further research with a larger group. Additionally, as a participant observer in all three studies, my research was inherently linked to my interactions with teachers both in the classroom, and in the PLP. I acknowledge that my main focus was on supporting teachers in implementing inclusive 3D instruction, and at times I may have made decisions that were good for teaching and not necessarily good for research purposes. Due to the nature of my work, I feel this is an unavoidable limitation and that the study still presents important information about teacher learning. There were also limitations in data collection and analysis. Students were difficult to hear on the video recordings and I often had to rely on field notes to provide evidence of what students were doing and saying. In addition, having cameras in the classroom likely changed the nature of classroom interactions between teachers and students – another unavoidable limitation. Finally, one potential limitation is that the teachers were implementing a provided curriculum in their classrooms. This serves as a benefit and limitation because while the curriculum served as one sources of support for teachers, we can't know how they would have developed lessons or units based on their learning. Perhaps that is a different study. Despite these limitations, I do believe the work as presented have important implications for multiple stakeholders within the field of education which I discuss in the next section.

Implications for stakeholders

An important takeaway from this work is that teachers – just as students – enter learning programs with a wide range of identities impacting how and what they learn, and what that learning looks like in practice. As such, effective PLPs must be responsive to teacher's contextual needs and goals, and provide space for teacher exploration and interpretation of ideas presented. When PLPs align with curriculum (Guskey, 2014) and allow space for teachers to make instructional decisions as professionals (Davis, 2003), teachers are able to combine curriculum and pedagogy in ways that meet the needs of their individual contexts. This work has implications for various stakeholders including teacher educators, policyholders, and professional learning providers. Teacher educators designing programs should consider using *The Framework for Inclusive Three-dimensional Science Classrooms* as a guiding pedagogy that students can make use of in coursework, internship, and eventually their career. Teacher educators also must understand that teacher learners require differentiation just as students do. Pre-service teachers enter teacher training with a wide range of learning experiences and backgrounds, and providing multiple entry points will be important for each individual's learning.

At the local level, policy makers should support the development and implementation of quality curricular materials and PLPs to support teachers in developing equitable science classrooms. To do this, resources must be allocated to designing and evaluating quality curricular programs and finding ways to get quality materials to all teachers. At the State level, policy makers need to recognize the importance of flexibility in implementation of learning, and encourage administrative support for teachers in promoting equitable opportunities for students in science.

Finally, this work has several implications for professional learning providers. Adopting pedagogies to develop inclusive classrooms maybe difficult for some teachers as student-centered methods disrupt traditional distributions of learning and knowledge in classrooms (Davis, 2003). As such, professional learning providers will need to establish positive relationships with teacher participants, where teachers feel safe to share, critique, and dissect beliefs about teaching and learning. Different teachers also may come from very different teaching contexts, and programs must be flexible and allow space for teachers to implement learning in ways that meet their student's needs. Finally, providing various entry-points for diverse teacher learning allows for teacher success regardless of learning preference.

Considerations for future work

Results of this results provide opportunities for future research including 1) examining student data as an essential aspect of studying learning communities and 2) developing sustainable, research based PLPs with the capacity to serve large amounts of teachers. Examining student data, including interviews with students, is important in determining how inclusive 3D instruction provides opportunities for non-dominant students. Preliminary analysis of Interactions student testing data showed no variation in scores by race or gender, rather variation in test scores can be explained how much teachers engaged students in various instructional practices (McGee, McGee-Tekula, & Duck, 2017). The gap in test scores between dominant and non-dominant students is widely publicized in educational research (Ladson Billings, 2006), and elimination of this gap by providing equitable opportunities for all students is worth exploration. Further, gaps in Interactions student testing data were described by how often teachers engaged students in particular practices and determining how those practices provide opportunities for non-dominant students is also important. The next focus for future research is 2) to consider issues for scale-up for a sustained PLP focused on inclusive 3D instruction. Five teachers from the Los Angeles Unified School District participated in this initial study, with the district providing 20 additional teachers with a year of sustained support the following year. I was able to facilitate both programs using my own philosophy of teaching, theories about effective PLPs, and my work with the initial group. However, questions remain about how to recruit, train, and hire facilitators moving forward. Researching qualities of effective PLP facilitators for urban high school teachers, models to scale-up such a program, and factors that may hinder implementation are other important foci for future work indicating a need to draw from literature on teacher professional learning as well as educational policy.

Reflections

In reflecting on my work with teachers over the last three years, I returned first to my Master's thesis which I wrote while teaching full time at an urban high school in the Midwest. I designed and tested an inquiry-based unit for students on protein synthesis – a topic my students routinely struggled with (Kolonich, 2011). Just as students in urban schools may have more to overcome to be successful in science, teachers too in urban schools may have more to overcome in effectively implementing 3D learning in their classrooms. *The Framework for Inclusive Three-dimensional Science Classrooms* was developed as a guiding pedagogy for all teachers, but may be especially important for teachers in urban schools working with non-dominant youth. One unexpected outcome of facilitating the PLP with teachers over the course of one year, was how very difficult it was to continually have deep conversations about teaching and learning, and to deconstruct cultural interactions between students and teachers. Forming strong, positive relationships was important in this work, but the work still had emotional impacts for teachers (as they reported) and for me as a facilitator. It was important for me to be flexible, giving them room to take and leave aspects of their learning, to challenge each other in the sessions, and ultimately, as professionals, to make their own decisions about instruction. Despite the difficulty and emotionality embedded in this work, I feel it was worthwhile – evident in the changes teachers were able to make in instruction, and my perception that each teacher was able to forge better relationships with their students.

In the introduction, I shared my experience taking my robotics team to their competition at a wealthy high school, and their astonishment that the bathrooms all had soap, toilet paper and paper towel in them for the students to use. The most devastating thing to me was the realization that not providing simple necessities to students like toilet paper carried a hidden message of inconvenience rather than value and respect. Similarly, I think that many of the issues that teachers in urban schools deal with on a daily basis –lack of funding, overcrowding, and frequent disruptions (Carter-Andrews, Bartell, & Richmond, 2016; Kolonich, 2011) - has the same hidden message of inconvenience rather than value and respect. While the ultimate goal of effective PLP is to effect student learning outcomes, it is important to remember that providing teachers with spaces where they are valued and respected is just as important for a PLP. We can value and respect teachers by providing PLPs where teachers' ideas are valued, where teachers have opportunities to learn in ways they prefer, and the freedom to make instructional decisions as professionals.

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