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**Promoting Science Learning and Scientific Identification through  
Contemporary Scientific Investigations**

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**Abstract**

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This dissertation investigates the implementation issues and the educational opportunities associated with “taking the practice turn” in science education. This pedagogical shift focuses instructional experiences on engaging students in the epistemic practices of science both to learn the core ideas of the disciplines, as well as to gain an understanding of and personal connection to the scientific enterprise. In Chapter 2, I examine the teacher-researcher co-design collaboration that supported the classroom implementation of a year-long, project-based biology curriculum that was under development. This study explores the dilemmas that arose when teachers implemented a new intervention and how the dilemmas arose and were managed throughout the collaboration of researchers and teachers and between the teachers. In the design-based research of Chapter 3, I demonstrate how students’ engagement in epistemic practices in

contemporary science investigations supported their conceptual development about genetics. The analysis shows how this involved a complex interaction between the scientific, school and community practices in students' lives and how through varied participation in the practices students come to write about and recognize how contemporary investigations can give them leverage for science-based action outside of the school setting. Finally, Chapter 4 explores the characteristics of learning environments for supporting the development of scientific practice-linked identities. Specific features of the learning environment—access to the intellectual work of the domain, authentic roles and accountability, space to make meaningful contributions in relation to personal interests, and practice-linked identity resources that arose from interactions in the learning setting—supported learners in stabilizing practice-linked science identities through their engagement in contemporary scientific practices. This set of studies shows that providing students with the tools and means of contemporary scientific inquiry allows them to gain conceptual development and proficiency with the scientific practices within the contexts of their lives, in ways that provided access to resources that promoted students' stabilization of practice-linked identities. For teachers implementing this instructional model in their classrooms, it brought up dilemmas and opportunities related to their school contexts and their personal history of instructional practices. The work collectively informs how interest-driven project-based science instruction can happen across a range of school contexts and how such models can support meaningful science learning and identification.

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## **Dedication**

To PVH, CVH, and JVH — Just find a place to make your stand and take it easy.

To the youth and educators involved in this study — You are all inspiring and I am so grateful for all that I learned from you.

## Chapter 1: Introduction

Science—including the frontiers of biology—is interdisciplinary, complex, often rooted in application to real world problems (NRC, 2009a). Increasingly, new scientific discoveries are made as engineering and computer science feats create new tools, techniques, and ways of understanding the world. Even with the ever-changing quality of scientific work, historically school science has been stuck within disciplinary boundaries and outdated knowledge. *The Framework for K-12 Science Education* argues that all students can learn science through instructional models focused on learning through the scientific and engineering practices. All students are capable of learning through engagement in epistemic practices. The turn towards practice-focused science learning opportunities called for in the *Framework* can be supported by multiple models of instruction. This dissertation examines how teachers can support students' interdisciplinary learning of biology through project-based, practice-focused, culturally relevant instruction.

Despite the social, political, and institutional constraints facing schools and teachers today, innovative and practice-focused science learning can happen in schools. Although there are compelling arguments that afterschool and informal learning opportunities offer flexibility—and therefore quality—that schools cannot (c.f., Heath, 2012), schools still provide the majority of learning experiences to all students. It is an equity strategy to focus on creating productive and innovative learning environments for students in school. All youth, especially those from non-dominant communities should be able to use science and scientific thinking in their everyday lives and have access to opportunities to pursue careers in science, technology, engineering, and mathematics (STEM) fields.

With this call for a broad scale shift in science education towards learning through practices, researchers have been investigating students' participation in practices, specifically modeling (Schwartz et al., 2009; Windschitl, Thompson, & Braaten, 2008), argumentation and explanation (Berland & McNeill, 2010; McNeill & Krajcik, 2008; Bricker & Bell, 2008), and obtaining, evaluating, and communicating information (Bricker, Bell, Van Horne, Lee, in press; Pearson, Moje, & Greenleaf, 2010). Within the current work, the challenge is two-fold: (a) to understand what it looks like when students learn in practices of contemporary science and how that work impacts students' connections to the scientific enterprise and (b) to understand how to support teachers as they engage students in learning environments focused on contemporary science. Youth should learn about and be able to engage in (to the degree possible) instances of scientific inquiry that are currently in use by scientists working today (Barab & Hay, 2001), which is in contrast to classical approaches to science education curricula that primarily engage youth in forms of inquiry and investigation from the history of science. We want students to learn about work being done on the current frontiers of interdisciplinary science. One way to do this is to create and study learning environments that leverage design principles from sociocultural and sociocognitive learning theories (Vygotsky, 1986; NRC, 2000) to cultivate powerful learning environments.

I argue that these powerful learning environments should be grounded in real scientific work where students are in positions to making meaningful contributions to science and their community through their work. A focus on contemporary scientific practices requires nuances in each practice dependent on the discipline and those participating in the practice. Biology as a field is becoming increasingly interdisciplinary especially with respect to the problems of the world the field is addressing (NRC, 2009a). The ways in which the practices of sub-disciplines

of biology are carried out is dependent upon the problem of study and the people collaborating on it with distinct yet complementary sets of expertise. For example, biology is becoming more and more computational and in need of computer scientists to build tools for housing and analyzing data, design models, and representations. Shifting science education to focus on engaging in scientific practices allows students to participate in science as a social endeavor focused on arranging chains of “epistemic alignment” from conceptualization of research questions to plans and data collection followed by analysis, explanation and argumentation, and ultimately communication (Rouse, 1996). This view of disciplinary learning through participation in epistemic practices extends the recent genetics learning literature that focuses on learning as development of molecular genetics reasoning and knowledge about genetic mechanisms (Duncan & Reiser, 2007; Duncan & Tseng, 2011).

Another affordance of instruction that engages students in practices is the ability to frame science learning experiences in personally relevant and consequential ways. Traditional science instruction rarely addresses personal or community relevance and social consequentiality, which perpetuates the view of schooling being a series of meaningless demands from the perspective of students (Bruner, 1996). Informal learning environments are often our best examples of places that support interest-driven and identity-related learning (NRC, 2009b). However, I argue that school can and should be a place where students can pursue personally meaningful and compelling subject matter learning. In school learning environments, we need instruction, curricula, and cultures that position youth as developing experts with a focus on building upon prior relevant interests and identities that can contribute to science investigations.

Engaging students in authentic and contemporary forms of science investigation through their participation in practices with personal, community, and scientific relevance holds great

potential for giving all youth opportunities to choose how science will factor into their current and future lives. Current science instruction is often missing the contemporary work of scientists (Lemke, 1990) and we need to develop learning environments that engage students in this work. By doing this work, schools can become a place of powerful learning for all students. It will also add to our theoretical knowledge base around cultivating powerful learning environments that take learning in practice in the context of schools seriously, while also informing how to build capacity in school organizations to engage learners in this way.

The purpose of this study is to analyze data from two distinct parts of a three-year research and development project to interrogate the ways in which students are supported to engage in scientific practice-focused instruction. First, I examine co-design collaborative discussions between teachers and researchers to identify the dilemmas that arise when teachers adopt a new intervention. Then, I look at student work across one biology unit to understand the ways in which students engage in scientific practices and how those practices are or are not productively aligned to support students' learning. Finally, with the assumption that all curricular materials have interest and identity-related implications for learners, I analyze the interest and practice-linked identity stabilization processes in play for students as they participate in practice-focused instruction.

### **Outline of the Study Design**

I studied a project-based, expert-connected curriculum model designed to promote science identification and learning through students' participation in contemporary scientific investigations. In the context of a year-long biology curriculum that was under development, this study focused on an eight-week genetics curriculum unit intended to engage students in their own DNA barcoding investigation in the context of other contemporary connections to genetics

(e.g., Foldit protein folding game play as a model of crowd-sourced science problem-solving and knowledge discovery, and genetics issues in the news such as an NFL player with sickle cell disease playing at altitude) and also included a broader look at teachers learning and collaboration around scientific practice-focused instruction throughout the course of the yearlong pilot curriculum implementation effort.

The study includes two interrelated components: (a) a design-based research (DBR) focused on design and implementation of the Genetics-DNA Barcoding unit in Winter and Spring 2012 and (b) a design-based implementation research (DBIR) study focused on the year-long support of seven teachers spread across the Pacific Northwest and Midwest of the United States in their enacting of practice-focused instruction during the 2012-2013 school year.

The year-long biology curriculum includes five units that engage students with contemporary biological topics: (a) phytoremediation, (b) DNA barcoding, (c) speciation of whales, (d) ecological impacts of climate change, and (e) modeling of infectious disease spread. The curriculum was designed using a next-generation model that included five key features and eleven design principles. The key aspects of the model are: (a) an online platform; (b) a Project-based Learning (PBL) instructional approach; (c) projects focused on scientific practices, crosscutting concepts, and core ideas; (d) involvement of disciplinary experts; and (e) integration of literacy in science. For the online platform, iRemix, by Remix Learning, was the platform used during the 2011-2012 academic year and Canvas, by Instructure, was the platform for the 2012-2013 academic year. While the platforms have varying approaches (e.g., social networking focused vs. learning management system focused) both allow for capturing student online participation (including course work, use of resources, peer-to-peer feedback, etc.) and interaction with peers, educators, and experts.

Each unit within the course was designed with a PBL instructional approach in which students were asked throughout the unit to tackle a challenge designed by the research team in collaboration with disciplinary experts associated with the key learning goals of the unit and the contemporary state of the fields today. . The PBL instructional approach is unique in its attendance to 11 key learning design principles, collaboratively developed in the partnership between Educurious and the UW team (see Bricker & Bell, 2012 for a white paper describing the principles):

1. Youth are positioned as developing experts.
2. Provide extended learning opportunities to engage in project- or problem-based learning.
3. Youth progress along competency-based learning pathways.
4. Provide continuous performance feedback and metacognitive facilitation.
5. Expert provide multi-faceted learning supports.
6. Youth learn contemporary knowledge, skills, and practices.
7. Build upon prior interests and identities of youth to promote seamless learning.
8. Promote personally relevant participation in authentic pursuits.
9. Cultivate thriving social learning networks.
10. Leverage video, disciplinary tools, and digital literacies.
11. Support multiple means of expression.

PBL instruction with these learning design principles leads to the following: longer units (six to eight weeks), student choice of contemporary project focus informed by their interests but constrained within the project topic space, time built in for expert feedback, deliberate

orchestration of expert-student interaction to allow for the growing of learners' social networks, and repeated skills and practices across the schools year—especially related to students' written work.

### **Research Methods**

The design-based research study (Brown, 1992; Design-Based Research Collective, 2003; Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990) investigated how students participate in contemporary scientific practices and how they build learning and identity trajectories through participation in those practices. Design-based research was leveraged as the high-level research methodology to address the need for rapid iterative design cycles of curriculum and testing across a range of classroom environments. Design-based research (DBR) allows for tracking iterative design of learning experiences through implementation, analysis, and redesign. Through this approach, we can document how students and teachers engage with the curricular design and whether or not the intended outcomes and desired types of interactions happen within a particular classroom setting.

I have approached the DBR work from the social practice theory perspective outlined above looking at both cognitive and cultural dimensions of activity. The data collection thereby included ethnographic methods (e.g., participant observations, semi-structured interviews and focus groups, and student work) along with qualitative methods (e.g., surveys, curriculum mapping) and quantitative methods (e.g., analysis of data from pre- and post-test items and student surveys related to their engagement and metacognitive thinking). The goal is to develop thick descriptions (Geertz, 1973) of learning ecologies in classrooms as teachers, students, and disciplinary experts interact around student participation in contemporary scientific practices. From these I can pull patterns and themes of activity. In addition to narrative accounts, I used

strategic video taping of classrooms in order to closely analyze learning arrangements and behaviors through video interaction analysis (Jordan & Henderson, 1995) of student participation in scientific practices and the identity implications of micro-interactional moments in the classroom (see Wortham, 2006; Health & Street, 2008 for related analytical work). These methods reflect the role of retrospective analysis in DBR by reconstructing the instructional theory of practice-focused instruction in PBL in chapter three and placing classroom interest and practice-linked identity moments within the broader case of stabilization of practice-linked identities in formal learning environments (Gravemeijer & Cobb, 2009).

The teacher-focused portion of this study is a design-based implementation research (DBIR) study that seeks to understand how the shared curricular intervention worked in similar and differing ways across a range of particular classroom sites under specific, local conditions. In this case, I looked at how seven pilot teachers were prepared to implement practice-focused instruction in their classrooms as called for in the year-long course they were appropriating. DBIR takes into consideration perspectives of multiple stakeholders in a collaborative and iterative design process with the goal of developing theory related to learning and implementations and capacity for system change (Penuel, Fishman, Cheng, & Sabelli, 2011). Penuel & Fishman (2012) argue DBIR is needed to address issues of equity of access to quality learning opportunities. At a systems level (e.g., students, classrooms, teachers, principals, schools, departments, and districts) DBIR addresses what adaptations are needed across the diversity in settings, a resource to support student learning. It highlights the emergent problems of educational practice encountered in the process and engages researchers and practitioners in the co-design and evolution of solutions and approaches in relation to those problems of practice. It also seeks to develop for organizational routines to intervene to address problems of practice

including specific professional learning strategies and instructional techniques used to support implementation.

One key to understanding the research and development work at a systems level—and therefore, the influences on the project and research findings—is the policy context of the overall project.

### **Design Elements and Process**

The research and development effort of the UW team was a three-year effort to create innovative, next generation year-long biology and English language arts courses for introductory-level high school students in ninth and tenth grade. Each intervention (biology and ELA) included the five or six project-based units per course instantiated on an online learning platform and supported by media (videos and digital games) produced specifically for the project and by The Educurious Expert Network (TEEN), a network of disciplinary professionals that connected with students through the online platform.

The project ran in two major development phases, Enactment and Pilot. These phases were of similar timing and structure for both the biology and ELA courses. However, I will describe how they were run specific to the biology course. The enactment phases lasted from Fall 2010 to Spring 2012 and the pilot year occurred during the 2012-2013 school year. During the enactment phase, research design teams (usually teams of two) designed and enacted each unit twice in collaboration with high school teachers and students. Researchers were in the classroom daily for these enactments, collected data, and made curricular revisions and design decisions throughout the enactments. Teacher collaborators provided feedback, co-taught the courses, and suggested revisions or activities to embed in the curriculum design. Teachers and students participated in only the enactment phase for one or two units, not the entire course. In one

instance, the Infectious Disease unit was enacted in high school health courses instead of biology, given the fit and timing of the collaborating school. These collaborations with teachers were set up through existing relationships with specific teachers, administrators, or districts.

During the pilot year phase, seven teachers across six schools (two were a pair and co-taught a bio-lit course) and their students from the Pacific Northwest and Midwest piloted the year-long biology course in their introductory level biology courses. The research design team worked to support teachers from outside of the classroom via face-to-face institutes, email, phone calls, and bi-monthly web-based meetings. When possible, researchers visited schools, collected data, met students, and provided in person support. The UW phase of the work included two additional curricular revisions, one representing the “final” curriculum piloted by the pilot year teachers and a final revision based on implementation data and teacher feedback that was completed in August 2013. As in the enactment year, the Infectious Disease unit was excluded from the biology course given time constraints of teachers, but two teachers also taught anatomy and they implemented the Infectious Disease unit in their anatomy classes in Spring 2013.

**Purposeful and Emergent Iterations.** The development work launched in Fall 2010 with about twenty individuals organized into two university teams, biology and ELA, and the Educurious team. The biology team designed, discussed, and shared concept units. We met with scientists, visited labs, and tested different scientific techniques and technologies to identify innovative, *Framework*-connected contemporary project ideas. We iteratively mapped curriculum elements to the learning design principles and made refinements from feedback across the project team. Once initial designs and plans were in place, we set up meetings with existing teacher-partners to seek classrooms for initial enactments. Over the course of one-and-a-half years, each unit was

enacted twice in a classroom near Seattle. Researchers were in the classroom with teachers during these enactments, and teachers decided the role the researchers played. This ranged from leading instruction on a daily basis to observing and providing technical support. From the launch, we began a management phase that was marked by continued development and research and transition into the pilot year, where we worked with seven teachers in six schools across the Pacific Northwest and Midwest to implement the entire year of curriculum.

**My Role in the Project.** I was brought onto the project for a small amount of time in fall 2010 to help think about designing biology units around interesting scientific issues. My background at that point included working with educators and geneticists to jointly develop curriculum through an NSF Math Science Partnership (MSP) awarded to the American Society of Human Genetics, and I had experience revising and researching student genetic and epidemiological research and learning through investigation of a database of survey data. I quickly became a more full-time graduate researcher on the project due to my interest, expertise, and the growing time commitment of curriculum development. Through weekly project meetings and planning sessions, ideas for curriculum units fell out, and we based initial brainstorm ideas on *A New Biology for the 21<sup>st</sup> Century* (NRC, 2009a), which examines how the field of biology is changing in current times to be more focused on interdisciplinary efforts that address human problems, and the draft versions of the *Framework* publically available during our design process.

Research and design teams formed around expertise and interest in topical categories. My time was focused on a genetics unit—inspired by the NYC Urban Barcode Project (<http://www.urbanbarcodeproject.org/>)—and the Northwest Association for Biomedical Research’s Advanced Bioinformatics: Genetic Research curriculum ([www.nwabr.org](http://www.nwabr.org)), a disease

unit (inspired by a TED talk about social networks and disease transmission) and a bioengineering unit focused on brain limb connections and artificial limbs. The genetics and infectious disease units both made the final cut of units. Leah Bricker and I, with input and review from Philip Bell and the entire Educurious team, developed both units and implemented each twice with partner teachers from Spring 2011 to Spring 2012.

The pilot year of the project began in Summer 2012, when we brought on three additional graduate students to continue the curriculum revisions and support teachers for the full year implementation. I transitioned to manage the biology team in both curriculum revisions and professional development design and implementation. As a team, we worked with the non-profit staff to plan and lead the face-to-face meetings with teacher partners and the bi-monthly online meetings. In addition, depending on the unit being enacted, we were consistently available to teachers for just-in-time support. Behind the scenes, we were developing resources, editing curricular materials, analyzing student data, and finalizing each unit after its pilot year implementation. In this leadership role, I was usually a secondary contact with teachers but was able to visit classrooms in the Pacific Northwest and play host to our teacher collaborators when they came to Seattle for face-to-face institutes. As they moved beyond the official partnership and into the 2013-2014 school year, I was able to stay in contact with most of the science teachers and hear about their students' successes and challenges, and their ideas for connecting projects to their local contexts.

### **The Dissertation**

In the following chapters, I examine the research and development effort at three levels of analysis to address open-questions associated with practice-focused instruction: (a) What does it look like for students to engage in practices over time?; (b) How does this influence their

thinking about possible futures related to STEM endeavors?; and (c) How can we support teachers to, in turn, support their students in participation of scientific practices? Beginning with co-design collaborations and teacher support, Chapter 2 presents an analysis of the dilemmas that arise when teachers implement a new intervention into their local systems. Then, Chapter 3 takes an in-depth look at students' participation in practices through analysis of their work during DNA barcoding investigations. Chapter 4 takes seriously the implications for students' perceptions of science in their lives through exploration of interest and identity development through engagement in contemporary scientific practices. Finally, Chapter 5 highlights the conclusions and recommendations across the three studies and describes the future work that will extend this dissertation study.

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## Chapter 2: The Co-Design of a Contemporary Biology Curriculum and Associated Dilemmas of Teacher Practice

Supporting teachers to “take the practice turn” in science education means shifting instruction towards engaging students in the epistemic practices of the sciences. The *Framework for K-12 Science Education* (NRC, 2012) calls for developing science proficiency among students through participation in eight scientific and engineering practices. The release and subsequent state-level adoption of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) prioritizes the need to understand how to support all youth in learning through engagement in epistemic practices. The *Framework* argues science learning for all students should integrate each of three strands: learning core ideas and crosscutting concepts through the scientific and engineering practices. This is also represented in the NGSS “performance expectations,” in which at least one aspect of each strand is integrated within each performance expectation for students. A major need for both research and practice is to understand how to support teachers to take up, adapt, and implement practice-focused curricula.

Practice-focused instruction is an implementation strategy to highlight the scientific practices in instructional models that “fit” with NGSS. There are many of these instructional models that have unique features to carry the vision of the *Framework* and NGSS that call for meaningful science instruction for all students. This is needed because we know that sociodemographic diversity in the STEM fields does not mirror the diversity of our society (National Science Board, 2014)—although broadening participation in STEM will improve the scientific knowledge that is produced (NSF, 2008) and help develop more scientifically literate citizens (AAAS, 1990; NRC, 2012). As teachers begin to encounter and implement these

instructional models, it is important to understand how their histories, local contexts, and reform demands shape dilemmas teachers face in their efforts to introduce a new intervention.

In this study, I analyze the dilemmas that emerge for teachers during the co-design and implementation of a scientific, practice-focused, project-based instructional model. The co-design of an enacted curriculum by teachers and researchers is a good place to observe dilemmas of teaching as they arise, while teachers grapple with them in their classrooms. Differences in educational contexts become evident as people negotiate the meaning of specific elements of the curriculum, and we can discover differences in their approaches and situations during these moments of change, aggravation, and attempted resolutions.

### **Theoretical Framework**

Teaching is dilemmatic—teachers sit at the nexus of competing goals and practices. As Dreier (2009) explains,

[People] live their lives by participating in many diverse contexts. These contexts are local settings which are materially and socially arranged in particular ways to allow for the pursuit of particular social practices within and beyond them; they are re-produced and changed by their participants and separated from and linked to other social contexts in a more comprehensive structural nexus of social practice. Accordingly, we must study persons as participants in and across particular contexts. (p. 196)

Dreier's theory of social practices situates practices in the complex interactions of people in the social world, across the contexts of their lives. The professional work of teachers is not limited to the context of their classrooms or schools. Teachers interact with colleagues, mentors, students, friends, experts, community members, and the sociomaterial features of these interactions

influence and reflect their instructional practices and professional learning (McLaughlin & Talbert, 2006).

When teachers choose to participate in efforts to change their practice, the effort enters into their existing nexus of social practices. Engeström (2011) describes the impact on an activity system when a new intervention is introduced:

No terrain of activity, no matter how stable and resistant, is free of inner contradictions...When an activity system adopts a new element from the outside (e.g., a new technology or a new object), it often leads to an aggravated secondary contradiction where some old element (e.g., the rules or the division of labor) collides with the new one. (p. 609)

These aggravations or dilemmas disrupt the existing system. The specific dilemmas I focus on in this study are the ones that arise when teachers introduce new interventions into their instructional practice and local contexts. Some dilemmas ultimately lead to changes in the learning environment that are desired by the participants; others lead to undesirable complications that need to be mitigated. These dilemmas are shaped by prior history of teachers' involvement with reform and by teachers' local contexts (Spillane, 1999). Dilemmas are also shaped by the characteristics of a reform or intervention. At the instructional level, they derive from gaps or inconsistencies between the instructional practices called for by the intervention and the teachers' local norms, routines, and practices (Tyack & Cuban, 1995). At the policy level, district policies could hinder or support implementation of a new intervention. These include schedules, resources, assessments, and allocation of responsibility (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). Allocation of responsibility related to administrative support of technology-based interventions is a building-level characteristic that

shapes the dilemmas that arise from new technological innovations (Fishman & Pinkard, 2001). Finally, new interventions need human, social, and material capital that is either developed or accessed and then activated to support implementation (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Spillane, Diamond, Walker, Halverson, & Jita, 2001). For Spillane (1999), teachers who were successful in changing their practice in response to reform efforts created networks of other teachers and local experts, participated in deliberations around the reform, and had access to material resources. Co-design partnerships between teachers and researchers (e.g., Linn, Shear, Bell & Slotta, 1999) provide one important model for approaching this work.

### **Teacher and Researcher Collaborations for Co-Design**

Design-based implementation research (DBIR) involves a design process that is responsive to the local context and builds capacity for sustaining change in context (Penuel, Fishman, Cheng, Sabelli, 2011). We know from organizational and institutional studies, as well as reviews of scaling curriculum efforts, that all interventions are affected by the affordances and constraints of the local contexts. The desires, concerns and knowledge of stakeholders influence the uptake of curricular interventions. The qualities of the local contexts matter as much as the qualities of the intervention. Nicolopoulou and Cole (1993) note: “the effectiveness of new programs will depend, not only on their intrinsic qualities considered in isolation, but on how successfully they can be integrated into the larger framework of the educational...institutions into which they are introduced (p.311).” DBIR allows for the development of educational products and programs that will travel more effectively across contexts. It also allows for the development of design knowledge for the new programs through examination of the variation of uptake of interventions across institutional frameworks.

In practice, learning about the frameworks of educational institutions requires extended communication and relationship building. One way to discover how curricular interventions travel and embed in different places is to support practitioners in their efforts to create productive adaptations in their local contexts. Productive adaptations use evidence of student learning to adapt curricula to be “responsive to the demands of a particular classroom context and still consistent with the core design principles and intentions of a curriculum intervention” (DeBarger, Choppin, Beauvineau, & Moorthy, 2013). Teachers need two types of resources to engage in productive adaptations—professional development around designing instruction and processes, as well as high quality curriculum materials (Penuel & Gallagher, 2009). Penuel and Gallagher (2009) found this combination to be the most successful in a study that compared the productive adaptation condition with a fidelity-of-implementation condition and a teachers-as-curriculum-designers condition. The productive adaptation condition supported higher levels of teacher and student learning, and teachers made clear changes to their teaching practice that were representative of the design principles, supported by quality teaching materials.

**Research Questions.** This study addresses two linked research questions focused on understanding the dilemmas of practice in the introduction and co-design of new interventions in the local contexts of teachers. I ask:

- What dilemmas of practice related to practice-focused teaching arise for teachers in iterative co-design?
- How do teachers make sense of these dilemmas, and how is this sense-making related to history, context, and the nature of the demands of the reform?

These questions were examined through investigation of the final year of a three-year research and development effort to create a year of innovative and contemporary biology curriculum.

## **The Collaborative Project Context**

This collaborative design work took place in the context of the research, development, and scaling of a new curriculum. The year-long biology curriculum includes five units that engage students with contemporary biological topics: (a) phytoremediation, (b) DNA barcoding, (c) speciation of whales, (d) ecological impacts of climate change, and (e) modeling of infectious disease spread. The curriculum was designed using a next-generation instructional model that included five key aspects and eleven design principles. The key aspects of the model are: (a) an online platform, (b) a PBL instructional approach, (c) projects focused on scientific practices, crosscutting concepts, and core ideas, (d) involvement of disciplinary experts, and (e) integration of literacy in science. For the 2012-2013 academic year, we used Canvas, by Instructure, as the online platform. The platform was learning management system-focused but allowed for capturing student online participation (including course work, use of resources, peer-to-peer feedback, etc.) and interaction with peers, educators, and experts.

Each unit within the course was designed with a PBL instructional approach in which students were asked throughout the unit to tackle a challenge associated with the key learning goals of the unit and the contemporary state of the fields today, which led to relatively long curriculum units (i.e., six to eight weeks of classroom instruction) and manifested in the addition of distinct features in the instructional model. First, students were given varying levels of choice and autonomy in each unit in which they could investigate a contemporary scientific issue that was informed by their interests but constrained within the project topic or technique space (e.g., the investigation could be carried out with the available tools). Within each unit, time and feedback supports were built in for disciplinary experts to give students feedback on their project work, as well as answer questions about core ideas and career/educational pathways. This deliberate orchestration of expert-student interaction allowed for the growing of learners' social

networks. Finally, the units within the course were designed to build upon each other with students repeating skills and practices across the school year, especially in relation to written work documenting scientific practice engagement.

For example, in the DNA Barcoding project, the focus of the genetics unit, students engaged in a species identification research project of their choice using the DNA barcoding technique. In general, this technique is used by scientists to collect DNA sequences and identify the species that they add to an open database designed to capture the biodiversity of life—making it accessible to scientists and the public. In the DNA Barcoding project, students wrote a research design plan, received feedback from experts and educators on the plan, collected samples, used wet laboratory techniques to extract the DNA from the samples, sent the samples to a company for sequencing, and then analyzed the resulting sequences using the online tool BLAST (<http://blast.ncbi.nlm.nih.gov/>) or the Barcode of Life (<http://www.barcodinglife.com/>) nucleotide sequence databases. In these projects, student groups chose and investigated a wide range of species identification questions such as: *What other organisms can be DNA barcoded from imitation crabmeat and how harmful can they be? And, are there ingredients in natural cough drops that are not listed on the package?* As students completed project work, experts—evolutionary biologists and geneticists—gave students feedback on their research designs and their proposals for funding. Students also accessed expert profiles online to learn more about their research and career pathways.

Each project was designed to integrate the three dimensions of learning in the *Framework for K-12 Science Education* (NRC, 2012)—scientific practices, crosscutting concepts, and core ideas. PBL projects designed around contemporary problems in the field are well suited to encourage students to engage in multiple overlapping practices of science because of the

complex nature of the tasks and the extended opportunity for investigation. The goal was to design curricular tools and instructional practices for learners that engage them in authentic disciplinary practices *while* learning about and applying the disciplinary core ideas and *making connections* to the crosscutting concepts. Epistemic practices do not operate in isolation in science. Students should learn how the practices are interrelated in the context of extended investigations through engagement in an unfolding, overlapping sequence of interrelated practices — or cascades of practices (Bell, Bricker, Tzou, Lee, & Van Horne, 2012). In the curriculum, students engage in and gain proficiency with a subset of these practices while working on contemporary problems in biology.

In addition to the contemporary science focus, students had access to disciplinary experts through the online platform, premised on the well-established finding that learning of complex subject matter is aided by timely feedback contingent to their thinking and work (NRC, 2000). In addition, it takes expertise to make expertise. That is, developing expertise is a social process that requires motivation to learn, access to relevant experts, feedback cycles for both experts and novices, and management of a productive learning affect (Bransford & Schwartz, 2009). Throughout the unit, students were prompted to ask experts questions or to request expert feedback on their project work. Students then used feedback to revise their work, which was part of the integration of literacy in the units. The literacy focus of each unit involved one or two Literacy Design Collaborative (LDC, <http://www ldc.org>) tasks that asked students to spend concentrated time reading and writing about their investigations in relation to Common Core State Standards in English / Language Arts. In the genetics unit, students wrote research design strategies to plan their investigations—including research questions, rationales, and

hypotheses—and research proposals for additional funding to wrap up the unit and propose future research that expanded their studies.

For teachers, the instructional model included PBL instruction, engaging students' interests and identities in a culturally responsive way, focusing on current interdisciplinary biology content and techniques, and leveraging learning technologies in instruction. All of these mentioned are possible points of dilemmas when they are introduced into teachers' local systems, especially given that we asked teachers to collaborate with us to implement all of these elements at once while navigating their own contexts. This included high stakes assessments and the roll out of Common Core State Standards. In-service teachers often have experience with some of these aspects of this ambitious instructional model, but at this time, no one had implemented them all at once. They need support to develop a pedagogical approach that supports the range of features (e.g., technology, current biological techniques) and principles (e.g., positioning youth as developing experts) in the instructional framework. Their learning in the context of this complex and ambitious instructional model is grounded in their own existing practices and instructional support systems, and these varied for each teacher in this study. For example, one teacher worked in a small project-based school with access to support for PBL instructional strategies but he did not have experience guiding students to work with contemporary biological problems. Another teacher also had PBL support through her school, but her job performance was largely based on her students' performance on the state's science graduation test and therefore she also spend time and energy on test preparation. This study explores how the complexity of the instructional model, local contexts, and long-distance co-design work relate to teachers' learning and implementation across a school year.

## **Organization of the Co-Design Implementation Effort**

**History.** The initial two years of the research and development project saw the research team working side-by-side, day-after-day with teachers in the classroom, in whatever capacity our teacher collaborators preferred. This ranged from researchers leading an entire class period to answering questions on the side while the teacher ran class. After school, the research team planned with teachers for the following days and weeks of instruction, identified needed resources, and designed activities based on students' expressed interests and capabilities. This iterative and collaborative design-based research process occurred through two iterations of each unit.

**Goal for the Pilot Year.** This led to the design of professional support with shared goals and practices from the very beginning of the pilot year work, especially focused on the learning design principles that shaped the curriculum. The first face-to-face meeting kicked off with a conversation devoted to the learning design principles, and from there, introduced the professional development goals as cultivating a professional learning network during the pilot year. To do this, we adhered to the following four goals:

1. Collaborate to support implementation as a network.
2. Build resources for the future.
3. Work on what is personally compelling to you.
4. Leverage variation in sensible ways.

The four goals were supported by six shared practices that we revisited in various ways across the year. The practices were: (a) coordinating logistics, (b) instructional planning and debriefing, (c) group analysis of student learning, (d) improve the enterprise, (e) remote classroom visits (which was optional for teachers), and (f) teacher research (which was also optional).

**Arrangement of the Co-Design Supports.** The year of professional support was designed as a space for collegial interaction where teachers could reconstruct practice (Kazemi & Franke, 2004; Little, 2003) to inform iterative design and support conversation between teachers and researchers. The nature of the project meant that the formal relationship between the research team and partner teachers was supported for one calendar year. However, the work spurred ongoing collaborations with specific districts and teachers. From a design-based implementation research (DBIR) perspective, the collaboration focused on identifying issues and solutions for resource development and theory building about professional learning and organization for educational improvement. The multi-prong support approach that included three multiday face-to-face meetings (July, October, and February), bi-monthly online meetings (called PLNs), weekly email “Hot Topics” blasts, phone, email, and listserv support, and just-in-time resource development and adaptation. The bi-monthly PLNs between teachers and researchers are the focus of this study.

For the pilot year of the project, seven teachers from six classrooms (two teachers co-taught a bio-lit course) collaborated with us to adopt and implement the Educurious biology curriculum. The teachers’ pseudonyms and school/community characterizations are listed in Table 1. The year was arranged as a design partnership between the seven teachers, the UW design and research team, and the Educurious Partners staff. The teachers were brought in as design collaborators with full knowledge that curriculum was in beta-mode on an iterative design cycle and would be changing based on their feedback, experiences, and recommendations. For example, as part of the partnership the teachers were asked to:

- pilot all five units across the year in a relatively controlled but flexible timeline;

- provide recommendations for changes to the curricular materials, project focuses and student products, the structure and presentation of curricular materials;
- recommend and demand resources for instant development and classroom use;
- test out and suggest avenues for delivery of materials on the platform;
- shape expert interaction organization, timing, and qualities of expert-involvement.

The bi-monthly professional development meetings has a dual purpose of helping teachers gain information and instructional guidance for anticipated challenges in the curriculum, as well as opportunities for us to elicit feedback about the curriculum and learning experiences available for teachers. For example, started each meeting with time for teachers to share successes, challenges, and questions, which often led to immediate discussion of those issues or celebrations.

### **Methods**

Drawing on the data collected in one year of a DBIR research and development effort, the study employs retrospective methods (Gravemeijer & Cobb, 2006) to understand how a shared curricular intervention brought up dilemmas for teachers in similar and differing ways across a range of particular classroom sites under specific, local conditions. Employing a grounded theory approach, the analysis was conducted through multiple iterations of thematic analysis of the discussions between the seven teachers and the research team across the academic year. Themes were cross-checked across multiple data sources and researchers involved in the activities.

### **Settings and Participants**

The analysis looks at the ways in which teachers from different school settings and local contexts take up and appropriate a practice-focused curricular intervention and how these produce teacher- and context-specific dilemmas. Seven teachers from three different general types of

schools participated in this study. I leveraged school types to describe the general affordances and constraints of the type of school but recognize each teacher is largely in a unique situation. Four teachers worked at schools that were part of a PBL network of schools. This network provided support for the schools to transition to small project-based learning schools with one-to-one laptops for students. Two of the three schools had previously taught interdisciplinary courses (e.g., bio-lit, bio-art, Physics/Algebra II) through a structural arrangement of having two teachers with differing subject matter expertise co-teach “double class” cohorts of students. The network offered PBL training and professional development opportunities for all their teachers, which is known to facilitate teacher learning of PBL instructional practices (Krajcik, Blumenfeld, Marx, & Soloway, 1994). In studies of district-wide implementation of PBL, researchers have found that professional development is vital for success as measured by standardized tests (Geier, et al., 2008; Finkelstein, Hanson, Huang, Hirschman, & Huang, 2010). These courses were supposed to be strictly PBL; however, the implementation of this pedagogical strategy varied across the three schools. The teachers and students worked on a shared online platform for curriculum and grading, which was developed for use across the network. Integrated technology use serves to connect students and teachers with each other, information systems, mentors, as well as acting as a resource to connect in- and out-of-school settings (NRC, 1999; NRC, 2009). Technology use has the potential to change relationships between learners, educators, and mentors (Borgman et al., 2008; Coburn, 2003; Elmore, 1996; Pea, 1993).

Within this network, teacher experiences varied. Francine had been teaching 29 years and worked in a large city urban district. Her class was interdisciplinary bio-art with a co-teacher who did not participate in the project. This meant Francine had about 70 students per class. Her

school was in its final year of funding from the PBL network and therefore often had technology issues with the one-to-one laptops. At one point in the year, Francine had four functional computers for her class to use. Mike—another teacher associated with the PBL network—had also been teaching 29 years and worked in a small city urban district. Mike taught biology and anatomy classes at his school. The technology at Mike's school was functional except for the rare occasions when sites were blocked by the district's policies. Kate and Meredith had both been teaching for 11 years and worked at an urban school in a mid-size city. Together, they co-taught a bio-lit course and both fully participated in the project. Kate—the literacy teacher of the pair—had previously been a biology teacher. Kate and Meredith reported to consistently integrate students' experiences across biology and literacy, which effectively gave them a double class period for implementing the intervention.

The second type of school was a STEM magnet school, which also provided one-to-one laptops for the students. It was a small school with capped enrollment. The enrollment process was run by self- or parent-nomination, and after 50 students per grade, they used a lottery system. There was not an application and interview processes, but students self-select. It would be classified as an inclusive STEM school because it didn't employ selective admissions criteria (NRC, 2011). The district and a non-profit jointly funded this school and the non-profit specifically focused on technology use and access to professionals in the STEM industries. The school model was developed from a decade of interdisciplinary afterschool programs created and run by the non-profit in non-dominant communities across the region. Overall, the school emphasized cross-disciplinary PBL in addition to traditional courses, test-prep, and career and college readiness. Laura was the only teacher from an inclusive STEM school. She had been teaching for 12 years, but this was her first year working in the state and at the school. Her

biology course at this school was a double period, double credit course, which allowed her to integrate additional instructional materials into the yearlong biology class. Laura had multiple years of experience teaching international baccalaureate biology courses at her previous school. The technology at her school usually functioned properly and if not, the non-profit funded a dedicated technology staff member for the school.

Lastly, two different comprehensive rural public schools participated in the project. In both these schools, laptops were not standard for all students, and they were either provided by the grant or by the school especially for the course. Both teachers were new to PBL instruction in the classroom, and teachers taught four or more preps (i.e., different courses) per day and coached a sports team. Out-of-field teaching is common in smaller secondary schools. Given the number of preps each teacher taught per day, neither teacher was originally certified to teach biology. Keith had been teaching for 31 years in the same rural school in the Pacific Northwest. In about the last five years, he began running projects with a handful of students after school but did not have experience with PBL in the classroom. He also had several significant community roles that he managed including volunteer firefighting and serving on the board of a local organization. Forrest had been teaching for 18 years and taught in a rural school in the Midwest and this was one teacher's first time ever teaching a high school biology course.

A summary of the teachers—pseudonyms are used for all teacher-collaborators—is shown in Table 1 and includes the experience, type of school, and geographic region of each teacher in the study.

Table 1. Teacher Collaborator and School Details

Pseudonym	Years Teaching	Type of School	Geographic Region; City Characterization	2012-2013 School Demographics
Francine	29	PBL Network	Great Lakes Region; Urban-Large City	28% White 40% Black 26% Hispanic/Latino 5% Multiracial <i>100% Economically Disadvantaged</i>
Mike	29	PBL Network	Great Lakes Region; Urban-Small City	48% White 38% Black 8% Hispanic/Latino 4% Multiracial 2% Asian/Pacific Islander <i>65% Free/Reduced Price Meals</i>
Forrest	18	Rural Public High School	Mid-West; Rural	100% White <i>36% Free/Reduced Price Meals</i>
Keith	31	Rural Public High School	Pacific Northwest; Rural	23% White 10% Hispanic/Latino 18% Multiracial 47% American Indian/Alaskan Native 2% Asian/Pacific Islander <i>52% Free/Reduced Price Meals</i>
Meredith & Kate*	11	PBL Network	Great Lakes Region; Urban-Mid-Size City	45% White 34% Black 14% Hispanic 75% Multiracial 1% Asian 1% American Indian <i>63% Free/Reduced Price Meals</i>
Laura	12	STEM School	Pacific Northwest; Urban-Large City	36% White 22% Black 21% Hispanic/Latino of any race(s) 29% Asian/Pacific Islander <i>55% Free/Reduced Price Meals</i>

\* Co-teach a combined bio-lit Course

\*\*Using 2010 Census data, a large city has a population greater than 1,000,000, a mid-sized city has between 100,000 and 1,000,000 residents, and a small city has less than 100,000 residents. Rural areas have a population of 5,000 or less.

## **Data and Analysis**

The data corpus used in this study of the teacher-researcher collaborations around the year-long curriculum enactment included audio, screen capture video and chat text of all 16 bi-monthly online meetings, fieldnotes and agendas from the three face-to-face meetings (including a week-long kick-off institute and two, two-day meetings held at intervals throughout the year), and email exchanges between researchers and teachers, which included the listserv we started mid year to support sharing of resources between teachers. Data analysis included initial coding of all 16, up to 90-minute online meetings first to identify problems of practice that frequently arose in the joint work. This process involved viewing the content of the audio recording with the presentation slides and accompanying chat data and describing its content in a spreadsheet (e.g., Jordan & Henderson, 1995). The audio recording of each meeting was transcribed. I coded teacher and researcher utterances based on the aggravations, contextual or local dimensions of teachers' practice that they discussed and anything else of interest that I identified in these transcripts (e.g., instances of positive disruptions or teacher reports on successes, motivations, and excitements about the instruction; Glaser & Strauss, 1967). This allowed for analysis of how the discussion of the implementation of a new intervention provides insight into how history, local context, and reform demands all figure in shaping what's dilemmatic for teachers. I supplemented this analysis with an analysis of email communication between researchers and teachers in order to triangulate (e.g., Merriam, 2009) the data sources and evaluate our emerging assertions and to build out additional detail around conversations that started or continued asynchronously.

## **Findings**

Findings emerged around three types of features that shaped implementation dilemmas in the literature: (a) features of the local context that matter, (b) features of the reform or intervention

that matter, and (c) the interaction between these features that matter. These themes represent practical areas of local variation in which the institutional frameworks and life histories of teachers influenced the implementation and productive adaptation of their work. The dilemmas of instructional engagement reported by teachers during our bi-monthly online meetings can be understood as the ways in which teachers make sense of and perform the professional practices of their work in relation to the linkages and separations across the practices of teacher's work lives as they navigate the variable circumstances associated with their implementation of a common curriculum product. The differences in teachers' dilemmas and sense-making vary from computer laptop access and reliability of the Internet connection to the school culture and students and teachers prior experience with PBL. Successful implementation at any sensible version of broad scale involves taking such variation into account—in terms of the implementation supports and in the analysis of local aspects of improvement.

First, I present six episodes that represent the co-design discussions that occurred as part of the teacher-research collaboration. Each episode demonstrates the dilemmas and affordances that arose for teachers across the year of implementation of a new intervention. Then, I look across the episodes to hypothesize how the features of the local contexts, the features of reform, and the interaction of these features shaped teachers' experiences with the implementation.

**Episode 1: Scientific practice-focused instruction.** Scientific practice-focused instruction—science instruction through engaging students in the practices of science—was a major focus of our co-design collaboration meetings throughout the year. Practice-focused instruction is deeply embedded in the instructional model and the goals of the course for the year, and it was a part of the instructional model new to all the teachers. The curriculum materials were built specifically to engage students in scientific practices that mirrored the

discipline-specific ways scientists do this work. One way for students to document their participation in epistemic practices was for them to produce written work, which is where extended literacy assignments were integrated into the curricular materials. Students' documentation of their practices was the most stable and shareable set of artifacts, which led us to use them to ground our conversations around students' engagement in practices. *An in-depth analysis of student engagement in practices is part of my larger dissertation study.* Management of teachers' dilemmas to support students in participation in the scientific practices included joint analysis of student work and discussion around instructional strategies. The first time student work examples were shared across the teachers was about one month into the school year, which was three months into the collaboration. The agenda for the online meeting was to review the goals and practices of our work together, to look at student work related to their planning a phytoremediation investigation, and to discuss logistics of students' setting up the first experiment cycle for that investigation.

This meeting occurred about four weeks into the school year and into the first unit on environment and human health that focused on a project related to phytoremediation. We had a bi-monthly online meeting discussing two scientific practices: *Asking Questions* and *Designing and Carrying out an Investigation*. Written outcomes of these practices were located in students' research design plans for the phytoremediation investigation they were designing using different species of brassica plants. In the curriculum, there was an embedded example of a completed research design plan to guide students' work. Once they completed their own research design plans, the curricular materials asked teachers to facilitate a peer review process on the online platform, which allowed for rubric-guided peer review. After peer review, students could revise their research design plans before they were submitted to experts who provided feedback on the

design. Ideally students were given time to examine the feedback before proceeding with the investigation. This process (draft plan, peer review, revise, expert feedback, examine feedback, proceed) was discussed between researchers and teachers during this online meeting. During analysis, it became clear that teachers approached this instructional sequence of PBL practice-focused instruction with different priorities and strategies.

The meeting was structured to discuss a specific practice using text from the *Framework* (NRC, 2012) to describe the 12<sup>th</sup> grade expectations of the practice, then used the curricular example of that written practice, and also pulled student work examples from multiple classes to ground the discussion in student work. The first piece of student work showed four examples of students' research questions and hypothesis for the investigation. A member of the research team started the discussion by stating an observation of the student work. He made an immediate connection to the learning goal specified in the *Framework* saying,

In the student example A, the hypothesis is a very concrete, predictable thing, that the plant will be dead ... but it's not from a point of view of the mechanism or the cause, which is the other part of that learning goal ... so that could be something to prompt students to think more about it.

His statement was a clear example of the type of reflection one can make about student work in the setting. This statement started a dialogue between teachers, initiated by Francine, who commented on student example B, "Question: How will the zinc make the plant die? Hypothesis: When I investigate my question, I think will find 100 grams of zinc because I want to see how much will kill my plant." Francine notes the incongruence in the student's statement and she kicks off the conversation in line 1.

1 Francine: I think that the student knows what they're looking for, but I'm wondering

2                   ... the hypothesis needs some work. ... *I think I'll find 100 grams of zinc*  
3                   *because I want to see how much will kill my plant* just doesn't seem to  
4                   connect. But I think it's a concrete question.

5 Keith:           I've been kind of struggling with this myself, because, Question D, it says  
6                   50 milliliters, 100 milliliters, 300 milliliters ... in Question B, they have  
7                   **100 grams**. So I think there is ... there is a real, um, and a disconnect here  
8                   and the students don't have a firm grasp ... what a concentration is or, or  
9                   what we're really going to be doing to ....

10 Meredith:     We told students to use **low, medium, and high concentrations** when  
11                   writing their research design plans. I know it isn't very specific but that  
12                   way they at least had some grasp of what they were talking about.

13 Forrest:       In regard to B [lettered student example], I have had a number of students  
14                   who have had the same idea, but wasn't sure if it **was something I should**  
15                   **correct or let them learn through the experiment?**

In lines five to nine, Keith builds off of Francine's example to note his struggle related to concentration of toxins and how they are represented in curricular materials. Meredith — in lines ten to twelve — provides a strategy or solution for Keith based on her experience with the same issue of helping students conceptually understand their research designs. Finally, Forrest reacts to the same example as Francine to voice instructional struggle about guiding students in PBL instruction.

In this short example of teacher talk around an excerpt of student work, I see the varying ways teachers respond to a discussion prompt, which surfaces the dilemmas that arise from their local contexts. As a reminder, this conversation happened very early on in the school year and in

our work together. The research team was thrilled to see the cohesiveness of the group and willingness to open up about struggles related to the work. Keith expressed a dilemma about concentrations and his need for support that arose from complicated, in-progress, curricular materials. The information he needed about concentrations for the investigation was located in three different documents across the unit. There was also a large portion of talk around logistical issues related to engaging students in the work. For Forrest, at this interaction at the beginning of the year, his dilemma—as voiced through reaction to student work—was whether or not to correct students, especially since they would still have a round of expert feedback. Through sharing these dilemmas early on, Keith and Forrest are able to get recommendations for managing them from teachers with more PBL experience.

Teachers from the PBL network schools shared strategies and tweaks, work-arounds for “faulty” or confusing curricular materials. They, too, noticed the issues with the lack of coherent information about concentrations but provided a work-around for their students. The teacher from the STEM school had not yet started the curriculum in her classroom, but she shared knowledge and strategies from previous teaching experience, despite being new to the school, area, and PBL. Practice-focused instruction crafted from the vision of the *Framework* and embedded into contemporary science PBL instructional units was new to all seven teachers, but this short interaction early on in the year foreshadowed the teachers’ histories, prior experience with reform efforts, and available-supports in the local contexts, all of which affect the ways in which they engage in local implementation and collaborative co-design conversations as a result.

The above conversation continued as we switched to showing student work examples of planning an investigation, including the student prompts: *How will you set up your investigation?*, and *What materials do you need?* I began this portion of the conversation on the

investigation practice in the phytoremediation investigations by bringing the conversation back to an instructional strategy that Kate mentioned related to the use of rubrics for students to analyze an example research design plan.

16 KVH: Kate, I was trying to ask you how you thought the methods for  
17 investigation, the section on the research design plans, turned out using the  
18 seed germination experiments?

19 Kate: Well, I ... the ... what was helpful was the example, was the seed  
20 germination. So that, um, you know, provided a really good guide for our  
21 kids, um, to, you know, to use. I think overall, the ... looking at the kids,  
22 um, just really being very specific.

23 ... Well, we use the, the example, um, in fact we had the kids, um, take the  
24 example and take the rubric, and had them score the example using the  
25 rubric, to kind of give them a really good idea of what the expectation  
26 was, and how ... and how to read the rubric to guide their, um, guide the  
27 detail they put in, which was really helpful for a lot of them to see that  
28 even the example had some, you know, had some strength and  
29 weaknesses. Um, the, the example had really strong, I thought the material  
30 ... the listing, the way the materials were listed and the method, um, you  
31 know, that, that was really, uh, very clear.

32 KVH: What did some of your students find that wasn't clear or not highly ... as  
33 highly marked on the rubric?

In lines 19-31, Kate shared the strategy she and Meredith employed of having students review the example using the rubric; research team had not thought of this strategy. The conversation

continued as I was curious about students' findings using the rubric on the curricular example (lines 32-33). Kate responded to my question starting at line 34.

34 Kate: Um, I'm trying to think. Um, we ... I mean, it ... the rubric was out of 24  
35 and most of the kids, the overall score was anywhere between a, I think  
36 the low was a 13, and the high was about a 19. And, um, I'm trying to  
37 remember specifically what the, uh, you know, where ... where [the  
38 example research design plan] was weak, um, I can't think of where it was  
39 weak, but I know ... **but we talked about it as a group that, you know,**  
40 **where was it weak, and why was it weak and the ones that you create**  
41 **that, you know, the students were to create, how to ... how to generate**  
42 **that so it would meet the criteria of the rubric.**

43 Meredith: [on chat] The rationale was weak on the example.

In lines 34-42, Kate discussed students' scores on the rubric and tried to remember what they found to be lacking. She also discussed strategy for having students reflect on what qualities their research design plans should have to meet the criteria of the rubric. In line 43, Meredith co-teachers with Kate, she remembered that the rationale was weak on the example. She used chat to add to Kate's explanation. Kate and Meredith acted as resources for each other and reconstructed moments of practice in conversations. The discussion continued for a few utterances about the rubric and then Mike transitioned the talk to peer-evaluation strategies.

44 Mike: When we, uh, set ours up, we, um, method, that's what the kids were  
45 having the most problem with. I said, you need to look at this being like a  
46 recipe, it's something you have to have step by step what everything is  
47 going to do, and if you can't do that, we'll need our peer evaluations. I said

48 if you don't understand what they're saying, then they shouldn't get a good  
49 score on that. And right there, you know, in the con ... in the, uh,  
50 comments, put down that they need to tell us exactly what they're going to  
51 do step by step, you know, and what they actually need.

52 And I know my students, some of you have already saw that with some of  
53 the examples I sent, have done that, and they haven't done a very good job  
54 with that. So with their peer evaluations today, I'm hoping, I'm doing those  
55 again after we get done here tonight, uh, that they're going to see  
56 comments tomorrow and hopefully we'll get them to the point to where  
57 they are setting things up correctly.

58 But, um, they did use the example, also, um, they had that to guide them,  
59 you know, give them an idea of what to do and all that, so ... um, but I  
60 think with the peer evaluations, it's a lot ... it's actually a good thing,  
61 because the students just aren't hearing from the teachers. They're hearing  
62 from them. And how I did it is I had my three classes, I had each of them,  
63 each class evaluate another class with, uh, being anonymous. They did not  
64 know who they were looking at, what group they were in, or anything, or  
65 even what class it was. And so they were pretty open about it and I told  
66 them to be that way. So, I don't know if that helps or not, but.

67 Forrest: [on chat]I really liked the peer review and wish, now, that I would have  
68 gone through the example design plan with the students. I was worried  
69 that they would just kind of "copy" that plan in creating their own. Am  
70 struggling with how much to guide the students and how much to let them

Mike — lines 44 to 66 — moved the discussion to talk about his experience with having students use peer review on their research design plans. He focused on method and students' articulation of method. He shared why he preferred the peer evaluation strategy over using the rubric to analyze the example and reflected on effective feedback strategies for students, specifically hearing from someone other than a teacher. To wrap up in lines 67-71, Forrest responded to both strategies shared by Kate and Mike and noted that he thought the peer review went well in his class but he wished he would have gone through the example as well. This was his second instance of voicing the struggle of how much to support students during PBL.

In a similar pattern to the previous analysis, teachers focused on instructional strategies for engaging students in scientific practices, this time in relation to designing an investigation. Kate kicks off this conversation portion by noting an adaptation she and Meredith made in their classroom. Together, they had students use the rubric to evaluate the research design plan example in the curriculum and then held a discussion with students about how they would make sure to include critical components in their own plans. The most interesting insight here was that the example was flawed, and students could discuss what was lacking in the example. Next, Mike followed up by talking about his experience with peer review and how he used it as a tool to improve students' investigative plan. Finally, Forrest re-voices his struggle with how much to guide student in their work. Before this discussion, he was worried about sharing the example with students because he did not want them to copy it. But Meredith and Kate's instructional strategy changed his mind about this. So without experience in PBL, this dilemma of guidance is foregrounded. Others have worked it through already, or have resources that structure student-led investigations that they think are effective, help them manage instruction. This "rubric and

evaluation of an example” strategy was adapted and it became a staple instructional strategy in the remaining curriculum units.

The dilemmas vary widely from navigating different PBL models in PBL-focused schools while trying out new instructional approaches like peer-review to figuring out messy curricular materials and how much to support students in their endeavors. The interaction between rigorous learning, engagement, and autonomy for students is a dilemma that was present in all levels of our work from curriculum design to the pilot year of implementation.

**Episode 2: Integrating activities into PBL units.** An important design challenge encountered early on in the project was to create learning experiences that were both academically rigorous and emotionally engaging for learners. This continued to be a focal point of the work as the pilot year began, and we expressed this perceived duality as something the research team believed to be a high leverage point for students’ learning. The design pursued the strategy that complex, professional forms of scientific work that allow students to explore personally relevant issues can be both rigorous and engaging and can happen in formal learning environments.

In addition to the larger PBL projects, each unit also included smaller sub-activities that supported students in understanding core ideas related to the unit and project work. In the genetics unit, we incorporated a study of inheritance using *Drosophila* flies as a model organism. A version of this activity is a standard Advanced Placement laboratory, and therefore multiple supply companies have curricular kits with all of the necessary materials. We designed supporting materials to link the model organism work into our curriculum unit, since it allowed for science investigations with great conceptual learning potential. During the pilot year, the pragmatics of unit timing meant that all but one teacher started the fly breeding between

Thanksgiving and winter break. Carrying out an investigation related to inheritance requires breeding multiple generations through specific genetic crosses and analyzing the data related to the appearance of specific traits. This means you need sufficient instructional time, flexibility, and patience, which no one had the luxury of during the condensed time between two holiday breaks. Six of the seven teachers experienced this dilemma of time constraints. Laura had to wait until after the new year to begin the activity because she had double periods of biology class and started the curriculum year later than the other teachers. This dilemma created complicated circumstances for carrying out the activity in the classroom. Yet, each teacher implemented the *Drosophila* breeding in his or her classroom with great enthusiasm. It was the most talked about curricular piece related to student autonomy and engagement in the first three months of the school year. Teachers' response to this dilemma differed in the way they reported reactions to the complexities, which was related to whether or not they had experience with *Drosophila* breeding. With the time to implement, Laura—the STEM school teacher—was impressed with her younger students doing higher-level work with *Drosophila*. She was new to PBL instruction but previously used a similar *Drosophila* lab activity with her International Baccalaureate (IB) students at her previous school. She drew on past individual experience to gain the confidence she could implement this activity with younger students, and she chose to order flies with characteristics that were more difficult to work with. She thought the curricular materials supported students to do a level of work she would not have asked them to do normally. Because of her previous experience, she was able to more expertly guide students in techniques for handling the flies and designing the crosses.

In contrast, the rest of teachers were new to the *Drosophila* breeding activity and faced the time dilemma, which led to basic technique issues associated with handling the flies as their

main line of discussion around the activity (e.g., figuring out how to anesthetize the flies without killing them or understanding the need for virgin flies in crosses). However, teachers reported that this dilemma turned into an affordance for students to become the experts in the classroom. Keith noted, “I’m getting some fly experts. They’re just, yeah, they’re just some kids that are a lot better at figuring out how to handle the little critters, and we’re getting better at, at not killing them ... there’s a technique to it, and we’ve all learned.” He noted he was on the same learning plane as his students, and they all had to learn about how to work with the flies. In his talk about this activity, he positions students as experts in the classroom and as needed learning partners. For students to learn *how to learn*, it is important for teachers to model for students what is like to be a learner rather than be the holder of all knowledge (Brown & Campione, 1994). The *Drosophila* work provided an opportunity for this instructional switch in this classroom. Keith led the activity in this way out of necessity. He saw it as a low stakes activity, since the timing dilemma had already ensured the activity would “fail,” and given his inexperience with PBL and competing responsibilities in his teaching, this was something he could hand over to students without repercussions.

Francine reported managing the dilemma in the same way—by turning over control to her students— and saw student engagement skyrocket. She needed students to help manage the work. She said, “I’ve got kids coming in after school counting flies. They want to use some of the extra flies to set up extra crosses. I have kids staying after school, even like Friday ... they’re really, really engaged with this.” The *Drosophila* work gave her space to turn control over to the students, which resulted in behavior (e.g., coming in after school) that she associated with high levels of engagement.

In this episode, implementation of a new activity under a time constraint dilemma led two teachers from very different context to report similar dilemma management strategies, while Laura's experience with activity and lack of a time dilemma led to her reported successful implementation with younger students than she had experienced before.

**Episode 3: Coordinating technology.** As co-design collaborators, the teachers were working with a one-to-one laptop-designed curriculum in a new online platform across varying levels of technology access. This episode represents the dilemma that arose when four of the teachers needed to coordinate different technological aspects of the model with technology in their local contexts. The schools in the PBL network had an existing online platform for instruction, grading, and communication that did not interface with the online platform used for curriculum delivery. This was an especially frustrating dilemma for Kate and Meredith, who used the network's platform in daily instruction. This was the major design challenge related to technology that had to manage. The issues included: students' difficulties navigating between platforms, teachers and students' preferences for using the platform they were familiar with, and the consideration that grading and parent communication had to live in the networks' platform. Kate and Meredith had an existing instructional strategy to give students agendas on the platform for every day of instruction. They resolved this platform communication issue by building these agendas for each day on the network platform linking to the new intervention's platform. In a co-design discussion, the researchers and teachers decided to make student-facing agenda pages of each section of instruction. This change was implemented in the second unit. Kate and Meredith then copy and pasted those agendas over to their platform. Francine and Mike had more flexibility in their school settings and they chose to engage students on the intervention's platform and continue with grading and other administrative tasks on the network's platform.

These agendas were popular for all teachers, and we kept the format into the final curricular revision.

**Episode 4: Attending to assessment demands.** Teachers in all states and schools are beholden to the current assessment systems of their local educational institutions. Teachers from schools in this study encountered assessment demands at all levels of an assessment system, from course grades to high-stakes state testing throughout the school year as they implemented the curriculum. These ranged from learning to give grades in PBL to the link between standardized tests and teachers' review and pay. The characteristics and commitments of each school arose for teachers within a contemporary science practice-focused curriculum implementation effort and impacted how dilemmas related to assessment. In this episode, I describe three instances of the assessment demands within the context of the historical circumstances of the teachers and the goal of piloting the intervention, since they highlight important theoretical issues and practical constraints associated with going to broader scale. Across the teachers, three types of assessment dilemmas arose:

1. Doing course grades in the context of PBL.
2. District assessment models and PBL.
3. High stakes test preparation taking over instructional class time.

***Transition to PBL grading.*** How to support students and organize PBL instruction in the classroom was the dilemma in both rural schools where the teachers were new to PBL and contemporary science projects.. For Keith, the transition from straight textbook and worksheet instruction to the contemporary science PBL instructional model created an instructional practice disruption specifically related to course grading. In one meeting, he attributed this to the classroom habits of his students saying,

In my situation, there are just certain kids that are a lot harder to get up-to-speed or ... actually finish their work or get it submitted ... then it's just like that this week is kind of critical because, um, mid-quarter grades were due today, so, you know, I ended up spending more time on it than, than before.

Grading in PBL instruction took more time and was not as straightforward as his previous instructional model—which is a leading issue given that he had multiple preps and several other professional responsibilities. He wanted to maintain his grading strategy based on his former instructional model but understood he needed a new strategy. The grading dilemma was embedded in local classroom circumstances with a complicated, underlying historical and cultural context. Keith's school is primarily attended by youth from a single non-dominant community, and there is a sense that the students are not consistently challenged with ambitious instruction across their schooling experience.

First, Keith articulated his goal was to see a seamless transition from worksheet grading to PBL grading, in terms of time and understanding this new version of assessment. However, the curriculum called for group work, revised drafts, long periods of time working on one document, the use of technology, and increased student autonomy. Each of these aspects was new to him, given he had a very refined, particular instructional model based on his 30 years of teaching at the school. There was a large gap between his previous instructional practices and those called for by the new intervention. During the time he was experiencing this dilemma in the grading shift, the research team often fielded calls and emails about building in more assessment moments into the curriculum so he would have more data to use for grading. This resulted in approximately bi-monthly online quizzes designed into the curriculum units starting with the second unit. In addition, while small steps of progress were being made during the pilot

year, there was a clear discourse across the entire school that the students were less capable than students at other places due to a collectively held deficit view of students. This is evident in the beginning of Keith's quote above, "*in my situation.*" He was having difficulty deeply engaging all of the students in this more ambitious form of instruction, which led him to wonder initially if the curriculum was too ambitious for his students and his instructional paradigm. Over the course of the year, to manage this dilemma, the research team worked with Keith to employ strategies to keep PBL in place, but also to help to alleviate the struggle of tracking and grading students' online group work. One of these strategies was to print packets for students of all the documents they would need over a number of weeks. This represented a compromise between the old worksheet model and the new practice-focused model. Keith's previous experience with project-based learning was in an afterschool program where he worked with a small number of hand-picked students, which might have helped reinforce the assumption that not everyone is ready for complex project work. However, during the year when my colleagues and I were able to visit the school and facilitate some of the instruction, he noted that his students generally could do more ambitious work when the researchers were there. By the end of the year, he thought the curriculum engaged the students surprisingly well and he was excited about and committed to using the curriculum for the next school year—which he did. The co-design collaboration with these teachers allowed for us to make quick and iterative changes to the curriculum materials and the user experience of those materials that were responsive to the local contexts of teachers. As a research team, we decided to accommodate these needs for more regular assessments because as collaborators for the whole school year, we needed to be responsive to structures (e.g., grading periods) that could cause additional unexpected dilemmas that might add up and become unmanageable for teachers over time, thus making future scaling efforts unlikely.

Teachers in the other two types of school had a more grounded foundation for grading and were focused on different aspects of assessment as they related to the instructional model.

***Standards-based grading and the new intervention.*** For Laura, the teacher at the STEM school, her assessment dilemma focused on linking the standards-based grading required by her district to students' written products, online discussion contributions, quizzes, and culminating project work and assessments. After 11 years teaching elsewhere, she was in her first year of teaching at a relatively new school, in a district with standards-based assessment requirements, which needed to be aligned with her implementation of the curriculum.

At the beginning of the pilot year, Laura managed this dilemma by asking for assistance in mapping the district's learning targets for standards-based grading to the places in the curriculum ripe for assessment of students' progress related to the learning target. Over the course of the year, she began to do the mapping herself. Her strategy for making this visible to students was to place the learning targets directly into the heading on the platform associated with the assignment or task being assessed.

Seeing this local standards mapping as a possible dilemma across contexts, the research team provided a similar support to the other teachers in the study, as part of mutual problem-solving work across states with differing local and state-level assessment demands. In January 2013 before the official release of NGSS, in order to help guide the pacing and planning for the rest of the school year, we made a map of the currently adopted standards and the curriculum units for each state and shared the document with teachers to scaffold a conversation around what future curricular materials they needed and to provide visible evidence for a decision to switch the order of the final units in order to make sure students had access to the most relevant core ideas for their state requirements. This standards alignment tool made it possible for

teachers to navigate dilemmas introduced by the new curricula. After sharing this document with teachers, Francine wrote,

I just wanted to drop you a line and say that the standards document you created is really amazing. Thank you! ... That must have taken you many, many hours to write. It is a very useful tool for us as we write and submit project plans to our principals.

In the network of schools in which Francine worked, every major instructional activity was supposed to be couched in a PBL unit, and in this particular school, teachers needed to document each project using a project plan connected with state standards and submit it to their principal. This confirms that the work benefited both the project's efforts to implement curriculum but also teachers' individual efforts to document their work for the year. It also highlights the kind of locally contextual product that is needed to support implementation in a variety of educational settings.

***High-stakes testing.*** Finally, the third category of assessment concerns was related to the high-stakes assessment in each state and their relation to teachers' performance reviews.

Teachers at the STEM school and rural schools (two different states) reported fewer concerns about their state assessments. In the STEM school, the principal promoted a view of state tests as low-stakes for the school, and therefore protected teachers from being evaluated based on their students' scores. In one of the rural schools, teachers adopted a relaxed view of the test scores, possibly due to the perpetual underperformance across time. In the other rural school, I do not have data as to why it was not presented as a dilemma by that teacher. However, two of the classrooms in the PBL network set significant instructional time aside during the school year specifically for test preparation related to the states' tests. Francine shared her struggles with

balancing her commitment to the project, implementation, and her need to attend to the students' preparation for the test. In December, she told us,

I'm going to have to really start to think about our high-stakes test ... we have the [state test] coming in the beginning part of March, and I'm very concerned about it ... frankly, my job performance depends on the kids' results.

Forty percent of her professional performance assessment was directly connected to students' improved performance on the state science test. A major issue that influenced this dilemma was that although she only taught biology, the test also included concepts related to physical and earth sciences, and those items could count against her on her performance. Therefore, to manage this dilemma, she decided that she needed to devote weeks of instructional time to test preparations for her students. To support this, the research team worked with her to make planned adaptations and cuts to the units so that her students would be able to participate in the important pieces, but she would have time for focused test preparation. This was a huge struggle and disappointment for her because she knew student engagement in the contemporary science project work was very high, and she recognized their participation as key to their academic growth. The structural details of the state assessment that ensured student performance on multiple subjects tested impacted teacher performance review directly and compromised the teacher's ability to cultivate powerful learning experiences for her students. The teacher merit dimension of the test is what ultimately guided her decision to focus on test preparation.

In summary, dilemmas are shaped by the assessment practices and struggles of teachers in their contexts. These practices vary by school and teacher and the support needed to manage the dilemmas varied from formatting student documents to be printed in packet format to

figuring out thoughtful ways to cut down unit time while still engaging students in the contemporary scientific practices and projects.

**Episode 5: Building students' social learning networks.** Students' social learning networks consist of the teachers, peers, family members, and disciplinary experts that they interact with to deepen their learning. Finding time and developing strategies for facilitating students' interactions with experts was a dilemma in relatively constant need of conversation, problem solving, and support in teacher and researcher discussions. During the pilot year, project staff recruited experts, conducted background checks and an on boarding process, and managed experts' entry into courses on the online platform. This was the first time the research team worked as an external group to implement expert interaction at broader scale, and this was a dilemma shared among all teachers and heavily managed by the collaboration throughout the year by testing and refining strategies for supporting expert-student-teacher interaction. Figure 1 shows a timeline of strategies and teacher response and recommendations for the strategies throughout the school year. For example, at the outset of the year, all teachers experienced a dilemma in streamlining expert-student interaction caused by incongruities between the communication strategies, online technology platform capabilities, and the curricular material instructions. This occasioned a re-design that included developing new training materials for experts, teachers, and students and cutting out additional technologies to use to support expert-student interaction (e.g., VoiceThread). After the dilemma was managed, the research team and the Educurious team built in more sophisticated interaction strategies that could be tested at a larger scale. These included a videoconference meeting between teachers and their assigned experts at the beginning of a unit to increase transparency, encouraging teachers and experts to exchange goals about expert participation, and efforts to increase accountability on both sides—

teachers and experts. Before these meetings, expert-teacher interaction was often strained, and both project teams were often mediating between them to make sure experts gave students feedback on a reasonable timeline relative to classroom pacing. After the meeting, one teacher noted, “Meeting the experts makes me more accountable.”

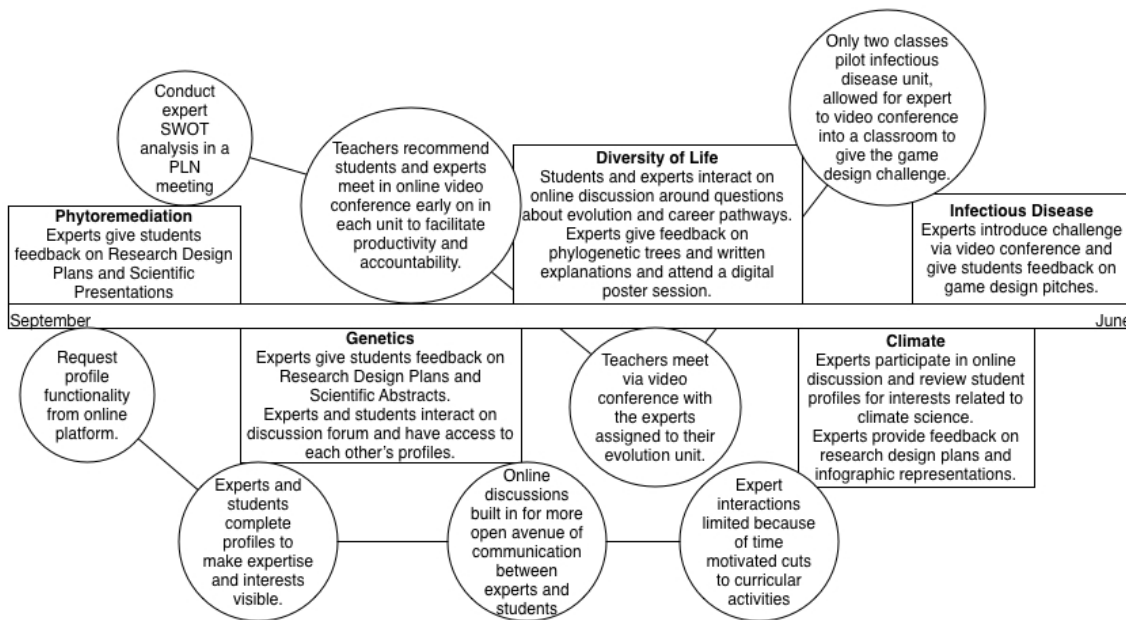


Figure 1. Timeline of expert-student interaction strategies (*circles*) used during the five curriculum units (*rectangles*) across the pilot year.

For teachers, facilitating expert interaction adds another level of management and planning on top of an already complex curriculum model. This part of the model is the first to be sidelined by teachers when time is tight—experts are difficult to communicate with and expert interaction is viewed as an added bonus but not an absolutely necessary component for students learning. That said, across all three types of schools, teacher-facilitated moments of interesting interaction and feedback between experts and students occurred with various strategies of uptake and implementation. Teachers were very supportive of the idea of expert involvement and appreciated it when it went smoothly.

Previous experience working with experts from outside the school and existing school culture were two main factors that shaped the dilemmas teachers experienced in implementing this portion of the instructional model. In the PBL network schools, implementation strategies varied by teacher and everyone ended up cutting instances of expert interaction because they needed to set aside time for state test preparation. Another dilemma evident in co-design discussions was how to support students in the uptake of expert feedback. Each teacher reported managing this dilemma a bit differently. For example, Kate and Meredith set aside time for students to share feedback from experts with the whole class because the students were so excited about it and because it allowed for all students to have access to general feedback from different experts. Kate—a co-teacher of the bio-lit course—really appreciated that experts would give feedback on students’ grammar, which lent more weight to the grammar-related feedback she gave to students. Given Kate and Meredith’s previous PBL experiences and a network culture of sharing student work outside the classroom, they were not hesitant to do so and had sophisticated strategies for managing the process.

Forrest expressed a similar challenge of managing students’ interaction with experts so they could use the feedback in their revision process. Some experts gave very specific feedback that students could easily understand and use. But at least one expert wrote a letter that frustrated students with too much information. In this case, Forrest implemented a strategy of reviewing expert feedback first, highlighting relevant actionable pieces and asking students to pay specific attention to those highlighted pieces. For him, this was part of learning how much to support and guide students in this contemporary science PBL instructional model. It is also the case that experts often also need to learn how to give constructive feedback to students.

Facilitating communication between experts and students was difficult for Keith in the other rural school at the beginning of the school year. He was not comfortable sharing student work in draft phases because he was entirely new to the process and did not want their work to reflect poorly on his classroom, school, or the students. At first, his strategy for managing this dilemma was to email student work to the experts instead of going through the platform, but he eventually shifted to having students submit work to experts themselves. Throughout the year, he encountered issues with the technology used to track student-expert communication, which continued to lessen the opportunities for meaningful interaction.

Laura's STEM school had an existing culture of expert involvement—especially involving technology experts from local companies—coming into the school to co-teach courses or attend student exhibitions. Even though she was new to the school model, she could leverage the history of ongoing support from her school, as well as the experience her students had working with experts. In addition, a handful of students in the biology course worked in a local cancer research center side-by-side with scientists conducting research. Laura immediately mastered the process of connecting students with experts through the online platform, but there were times where experts would not get back with feedback in time. Experts were volunteering their time to participate in this effort, so this was not uncommon (Lawless & Rock, 1998; Means, 1998). Over the course of the year, Laura was disappointed in the overall expert component of the model and continued to brainstorm strategies for facilitating more meaningful interaction, including face-to-face interaction early on in the unit and leveraging local experts who are able to visit in person and have more buy-in to the school and community. This desire, along with a graduate student's research interest, led to a joint grant proposal to support university scientists learning about and participating in science education through partnership with this STEM school.

This grant was recently funded and will continue to support direct expert involvement in student projects at the school.

Coordinating expert-student interaction takes time, patience, and student autonomy to follow through on the process. The dilemma that arises—especially in rural schools—is the tradeoff between the difficulty facilitating expert-student interactions and motivation to connect isolated students to experts. The novelty of this particular piece of the intervention was uncomfortable at times and it required fairly strict protocols for sharing work to ensure all parties knew where and when to look and what to expect. Overall, it took a couple months to get a clear and straightforward way to use the new online platform for submitting student work. Before this, students, teachers, researchers, and experts were utilizing various methods, sometimes leading to miscommunication and lack of feedback. Managing the dilemma did provide affordances for teachers. They reported that they appreciated the specificity of experts' comments and thought students paid more attention to expert feedback than they did to teacher feedback. Experts in close proximity to schools made themselves available to come in and support some activities and for continued collaboration. Teachers at one school also reported that experts were following and interacting with the school's events via Facebook. In other cases, the formal expert involvement allowed teachers to reconnect with friends and colleagues in different sectors and bring them into their professional work.

**Episode 6: Integration of literacy instructional sequences.** With the release of NGSS, there is potential overlap between the science and engineering practices students engage in and those of math and literacy (Stage, Asturias, Cheuk, Daro, & Hampton, 2013). Literacy practices of reading and writing of informational texts can be leveraged to support the investigative work of students (Pearson, Moje, & Greenleaf, 2010; NRC, 2012). In the initial design process of the

curriculum, with a commitment to students producing written work that mirrors contemporary disciplinary work (i.e., as opposed to typical school assignments), we created scaffolds and templates that supported students in demonstrating their engagement in scientific practices through written documentation. These documents included research design plans, scientific abstracts, proposals for future funding, elevator pitches, infographics, and scientific posters. In the initial design phase, we leveraged and extended the instructional model of the Literacy Design Collaborative (LDC) to design tasks and supports specific to the work of science professionals that helped students make connections between their work and the broader connection between literacy and science. This was a connection recommended by the funder, given they also funded the LDC effort. Elsewhere, we report that this approach can help students to “try on” forms of scientific writing and produce relevant texts that represent a hybrid space of disciplinary practices, school science, and their everyday experiences (Bricker, Klein, & Van Horne, in preparation). In the pilot year, the research team worked with teachers to reflect on the written disciplinary work of students as it connected to or resulted from their engagement in scientific practices and used this as a professional development strategy for examining student work and learning.

Students wrote research design plans in the first unit (phytoremediation) and the second unit (genetics), which encouraged them to write scientific questions, obtain and evaluate background information, and plan an investigation to address the research question informed by the background information. Between the two iterations of this written product, the curriculum prompted teachers to ask students to reflect on how their first foray into this work would inform the written work to plan their next investigation.

Early on into the second unit, we held a co-design meeting that included discussion around students' responses to these reflection questions. This discussion occurred because the two teachers that co-taught the bio-lit class brought up the success of this online discussion in their classroom and asked for more resources for supporting students in formulating scientific research questions. In the discussion, three teachers highlighted multiple aspects of literacy practices in scientific work and their relation to the goals of the instructional model in this discussion. We framed the discussion by collectively reviewing student answers to the prompt: *What did you learn from your first attempt at creating a phytoremediation-related research design plan that will help you make this research design plan for DNA barcoding even better, and how are the two research design plans the same and different?* I set up the conversation by providing student responses to the prompt that included:

- *be specific, back up your information, and do not use baby words;*
- *don't run with your first copy, revising is essential. Add details to make it accurate after easier to follow. Use graphs to show your results, and record as much data as possible; and*
- *I learned that doing a little background research can help you to make a good research design plan.*

Kate started the conversation by making a connection between student word choice in science to success on SAT.

72 Kate: [on chat] Not using baby words is huge. This practice will help them score  
73 higher on the SAT.  
74 [out loud] I guess I'm not just satisfied with writing it. But, as an English  
75 teacher, baby words is huge. Um, I've taught an SAT prep course. And

76 also done a lot with getting our kids ready for their English graduation  
77 qualifying exam. And, that word choice and using better vocabulary  
78 increases their writing scores so much. So getting them in the habit of  
79 using \$20 words, um, is so good. And so I ... I'm thrilled that we're doing  
80 that.

In lines 74-80, Kate further explained her point, noting the importance of using better vocabulary as a key strategy for students' future success. Francine followed up by discussing graphs and charts.

81 Francine: [on chat] Translating data into graphs and charts is also very important.

82 There are numerous questions related to data analysis on the [state test].

83 KVH: Thanks Francine. I think it's interesting how often that showed up. It'll be

84 different for the genetics unit [because the data is] translated into graphs

85 and charts, which [doesn't happen in the genetics unit]. So that's probably

86 a good way to think about the different ways of represent data ...

87 depending on what type of investigation you're doing. And we're hoping to

88 use some of the genetics data, too ... That will then get sort of translated

89 into different representations in the evolution unit. So, that we'll be a good

90 thing to carry through.

91 PT: [on chat] Super interesting to see how writing processes are highlighted.

92 Also neat to see the relationship between text and graphic, table. Really

93 methodical.

94 Mike: [on chat] I would agree with Francine with graphs and charts is important.

95 This is the biggest part of our [state test] science portion.

96 Kate: [on chat] Students see the connection between better background research  
97 and a better design plan.

Francine — lines 81 and 82 — noted the multimodality (e.g., Kress, 2001) of literacy practices in science, she coded students' responses as important because of the way data analysis shows up on the state science test. I then brought up that data representation and analysis changes based on the type of investigation underway and that students' use of graphs and tables for the phytoremediation investigation will look very different from the DNA barcoding investigation. PT, an ELA learning researcher, followed up by calling out the students' reflections on their writing process. In lines 94 and 95, Mike echoed Francine's point about representations as part of the state science test. Finally, Kate pointed out that the information practice and investigation practices are linked and students learned from their first research design plan that better background research can inform their own research.

In a transition to the next student question, I provided the group with student responses to the prompt that asked them to respond to the similarities and differences between the two research design plans. Student responses included:

- When we write the design plans, we should make them actually able to be done, not some plan that there is no way to do—that is what we did with the phytoremediation investigation.
- Our first project was day-to-day observation and this one is an experiment plan.
- We will not be using plants this time so we have to do a different way to decide if our data supports our hypothesis.

- Different scientific work is involved with DNA barcoding than phytoremediation. I also think that the current scientific work of DNA barcoding is more diverse than the current scientific work of phytoremediation.

In line 98, Kate noted that students learned from attempting research that was not feasible in the phytoremediation investigation that the technique needed to match the research design.

98 Kate: [on chat] Good reflection—learning from past failure.

99 Mike: [on chat] My students are being much more specific with their design

100 plans. My students have never been exposed to this before this year and

101 they are finding it a little easier. The students are finally getting the ideas

102 of why we revise. It also helps with student input and not just teachers.

In lines 99-102, Mike reflected on three key pieces of integrating literacy practices into science: (a) students and teachers alike are not used to doing the work in science classes; (b) experience with the science and literacy practices increase specificity in students' work; and (c) revision is necessary and students find it more compelling through a peer review processes to support revision.

These exchanges are representative of the entire discussion in terms of quality and participation. Only the teachers from PBL network schools participated. This was likely the result of a combination between Kate and Meredith's recognized position as sharing instructional strategies from their bio-lit course, so the others let Kate take the lead, and the fact that three teachers (Meredith, one from the STEM school, and one from a rural school) were unable to attend this PLN because of athletic coaching and family commitments. Kate and Meredith also emailed the joint listserv with ideas and sharing their strategies the most. They would share how

they kicked off each unit—a required element of PBL at their school—as well as resources and ideas for using them in the class. For example, Kate emailed the group to say:

This article demonstrates the relevance of our DNA Barcoding Project.

[Meredith] and I will probably incorporate it into a journal this week.

<http://www.cnn.com/2013/01/16/world/europe/ireland-britain-horses-burgers/index.html?iref=storysearch>. Enjoy!

Despite the low attendance, the discussion still bears importance for the ways in which literacy practices can be valued and attended to in science classrooms.

By grounding the discussion in students' ideas about the research design plan writing process and the links between the first plan they wrote, as well as the plan they were about to write for DNA barcoding, this discussion session highlighted students' reflection on the opportunity to grow in progression in practices across time. This is a main piece of the vision in the *Framework*. One strategy to trace students' practices performance over time is to locate scientific practice in the literacy practices of the disciplines. This includes recognizing how scientific and disciplinary literacy practices are the same and different across disciplines.

Through this conversation, dilemmas that arose for Kate, Francine, and Mike were visible. First, for Francine and Mike, the connection back to high-stakes assessment was vital and a motivator for their supporting students in the written work. Scientific representations are part of the multimodality of written scientific work, and this demonstrates the complexities in understanding how to use representations to analyze and communicate about data, especially in the context of assessments. Table and graph representations are common in school science and the exclusive use of them can make it difficult for students to broaden their views of science across disciplines.

Two teachers noted the prevalence of tables and graphs as they relate to data analysis on the

states' science tests. As students thought about the differences in the two investigations, they noted the scientific work of DNA barcoding is different from the scientific work of studying phytoremediation. To offset the dilemmas that arose related to representation and after multiple investigations using a similar template for documenting the research, teachers managed instructional strategies for helping students to understand that appropriate literacy practices vary by discipline.

For Kate, the dilemma she faced in this implementation and in her professional work overall was the need to facilitate the writing process in science as it includes literacy practices. She noted from students' responses that students talked of the literacy work in science as: consisting of the use of sophisticated vocabulary, using background research to make a better research design plan, and revision through a peer-review process. Kate managed this dilemma by focusing her efforts on helping students make literacy improvements that will benefit them on their college entrance exams (e.g., SAT) or English graduation exams. She was thrilled to see students noting that research design plans should include more sophisticated vocabulary choices. The takeaway here is the mutual benefit of promoting literacy practices in science: that engagement in scientific practices can support integration of science and literacy, and that strong literacy practices can support student engagement in complex intertwined scientific practices.

Finally, Mike's dilemma was related to his observation that on this second attempt at a research design plan, his students were doing much more detailed work. For his first attempt at this type of literacy work in the classroom, he experienced success. As part of this dilemma, he noted the importance of the literacy integration as a strategy for helping students to learn the importance of revision in science through the process of writing research design plans and getting peer review feedback.

Literacy practices in contemporary scientific work support disciplinary engagement in scientific practices, as well as multiple opportunities to revisit the performance of scientific practices in written format. The discussion around literacy practices in students' scientific work identified the constitutive pieces of interacting practices in a classroom context, specifically PBL network classrooms. The multi-subject course structural arrangement in the PBL network classrooms, specifically bio-lit, uniquely afforded integration of literacy practice in scientific project-based work. The teachers could structure class time so that the written, representative, and presentation work was completed in the literacy portion of the course. These findings also support the conclusions in Chapter 3: Epistemic Practices in Contemporary Science Investigations, in which students use background research to support the formation of arguments for continued funding, another instance of literacy practices supporting engagement in multiple scientific practices. Review from individuals other than teachers (e.g., other students, disciplinary experts) was often repeated by teachers as an important learning support.

### **Features of Dilemmas across Episodes**

Across the six episodes, I looked at the features of what shaped dilemmas across teachers' experiences of implementing the new intervention for an entire school year.

**Features of local context that matter.** There was a difference between the dilemmas teachers from PBL network schools faced and the dilemmas faced by the other teachers in the study. Teachers with past history implementing PBL had additional resources for making sense of the new intervention that allowed them to quickly manage dilemmas that emerged and then share their instructional strategies with others. In Episode 1, there was a common dilemma that the curricular materials did not clearly explain how to determine concentrations of chemicals. Teachers with PBL experience reported glossing over this dilemma, providing their students with

a solution and moving on, whereas teachers new to PBL got stuck on the dilemma. This is consistent with the finding that implementation efforts can be hindered when there is a large gap between teachers' familiar instructional practices and those required in the new intervention (Tyack & Cuban, 1995). The difference in this study was that more experienced PBL teachers were able to help new PBL teachers manage dilemmas, sharing instructional strategies specific to how they solved this issue.

A consequence of collaborating with teachers from a wide variety of contexts is that each teacher had different access to ongoing support from other sources (e.g., PBL network, STEM school) that provided additional resources for managing dilemmas. However, these teachers needed to coordinate their use with demands of the new intervention work. Kate and Meredith had ongoing support for PBL instruction and technology platform use, but they needed to coordinate the technology platform with their existing technology platform. For Laura, her school's ongoing support and connection to local professionals allowed her to manage dilemmas related to connecting students with experts. But because her school was small, she also had to coordinate experts for all students participating in the science fair, as well as plan the event and organize judging.

In addition to lacking the ongoing support of networked schools, rural school teachers also had to navigate the competing responsibilities and obligations in the implementation work which lead to logistical issues. Keith taught four different classes throughout the day, and therefore he had limited time to prepare for class each day, and he needed to figure out logistics first before moving into instructional strategies to increase students' learning and engagement. Logistics ranged from grading, to experiment set up, to computer maintenance.

Studies of accountability and PBL instruction have shown that students in PBL instruction out-perform their peers on standardized assessments (Geier, et al., 2008; Finkelstein, Hanson, Huang, Hirschman, & Huang, 2010), however, nuances arise from local contexts. For example, Francine needed to devote test prep time because she was accountable for students' performance on subjects she did not teach. Accountability and grading requirements and practices are contextual and shape dilemmas that teachers report, as well as how they manage those dilemmas. For Keith, managing the PBL grading dilemma meant printing packets of documents instead of using digital documents and instituting regular quizzes.

**Features of reform that matter.** In addition to the features of the context, features of the reform or intervention also matter for teachers who reported dilemmas. Material resources are required to enact innovative curriculum models, including both the curricular materials, as well as the resources for student engagement (e.g., scientific tools). Teachers need access to both the material resources and implementation support to make curricular adaptations that manage dilemmas in their local settings, which is consistent with work comparing conditions of teachers' support for their design and implementation efforts (Penuel & Gallagher, 2009).

The intervention also requires human and social capital needed to enact. This is especially important around the need for disciplinary experts to interact with students, which is a key feature for ensuring students have access to science instruction on the spectrum towards participating in real science (Barab & Hay, 2001; Pea, 1993). Schools with existing infrastructure and partnerships with local professionals face fewer dilemmas with implementation both from a practical standpoint and from an instructional standpoint. From an instructional standpoint, students have experience working with experts, using expert feedback for revision, and interacting with them in culminating performance moments.

The nature of practices themselves, as features of scientific practice-based reform efforts, has potential to shape implementation dilemmas for teachers. In this study, teachers reported dilemmas related to the supporting students posing scientific questions and planning and carrying investigations. Multiple efforts (e.g., Research + Practice Collaboratory, NGSX) are underway to recognize this common dilemma and resources are being developed to support teachers as they take up scientific-practice focused instruction.

Finally, intervention features that are influenced by the funder and national policy can shape dilemmas in teachers' implementation. In this case, both the funder and policymakers (e.g., Common Core State Standards and Next Generation Science Standards) wanted strong ties to literacy in science instruction, which led to a push to explore those connections in implementation work. The analysis in this study looked at teachers' management of dilemmas of literacy integration, which mainly focused on the students' use of language, the connection to high-stakes test, and students' seeing the value of revision in writing for science.

**Intersections between features that shape implementation.** If dilemmas arise that are due to both the local context and the reform, and a teacher does not have access to ongoing support either from a co-design collaboration or from existing support structures, the challenges presented by the new curriculum might overwhelm the teachers' ability to pursue goals embedded in the new intervention. This speaks to the importance of ongoing co-design collaborations to support the work as well as motivations for sustaining management of dilemmas across time.

### **Sustaining Management of Dilemmas in Implementation of New Interventions**

The seven teachers often shared feedback and thoughts on the overall experience and their students' experiences that motivated their sustained management of dilemmas in the sometimes

difficult implementation work. This was usually unprompted, tacked on to the end of an email communication with members of the research team. Given the complex set of work we asked teachers to dive into during an entire school year, their reflections and spontaneous remarks highlighted the importance of building social relationships and rapport in collaborative design partnerships. The collaborative work evidenced likely would not have resulted otherwise. These insights also highlight the need for future work on teachers' identity development as learners and teachers of science.

Overall teachers' reflections on the motivation behind managing dilemmas occurred in three categories associated with the work of teaching: (a) the quality of the year and relationships built, (b) the student experience, and (c) the purpose of teaching. Teachers reflected on the quality of the overall experience, including the co-design support and their in-classroom experience, as well as their feelings of belonging in the partnership with the research team. Keith wrote, "This is an incredible experience, thank you for including me in Educurious." Francine, one of the teachers who needed to carefully navigate her state assessments, specifically talked about relationships in one of her emails saying, "Thanks so much for all of your help throughout the school year. It was really a pleasure working with all of you and getting to know you." Finally, Mike likened the collaboration to family: "I have really enjoyed working with all of you, how you made us feel like family, and of course, teaching the course." The co-design context created sustained and supported teachers in working through dilemmas, building relationships between researchers and teachers in which the teachers trusted the researchers so if they tried a piece of the new intervention and it created a dilemma in their local context, the researchers would be available to help them figure out how to manage it.

Teachers saw affordances that arose from the intervention as directly linked to their students' experiences, which was another motivation for teachers managing dilemmas.. Keith noted that at least one student spoke to her principal about her experience; he wrote, "The girl [who DNA barcoded] the bobcat kitten told the principal that biology is her favorite class. She struggles at times but enjoys the projects." Mike felt through the course and support of his development, the research team made a difference for all his students. Laura asked the students for their reflections at the end of the year, and she reported, "There was an overwhelming positive feedback from the kids, as well, as far as how much they enjoyed the material and all the cool projects they got to do." In the work, teachers saw their students engaging in science learning that was beyond what they had expected, which led our teacher collaborators to reflect on their teaching overall. For teachers in the design partnership, focusing on engaging, contemporary projects was a powerful addition to their educational ideologies which are often in contrast to educational ideologies focused on preparing students for college through less engaging and poor instruction that usually defines entry-level college course. This demonstrates that it is possible to do progressive instruction in public high-poverty, complex educational institutions in a way that both teachers and students recognize as important to their own learning.

Finally, the most reflective of these communications came when teachers stated their thoughts on the purpose of teaching in the context of their experience during the year and their intentions to continue with the implementing the intervention. Through the management of dilemmas and seeing the positive outcomes of the work, Francine wrote to us, "I firmly believe that consistently expecting students to meet the high expectations of this type of rigorous curriculum is the only way that we can facilitate their academic growth." And she was looking forward to using the curriculum again during the 2013-2014 school year in order to "fine-tune

many aspects of the courses that [she] goofed up last year.” Mike, who had been a teacher for 29 years and was planning to retire within the next five, thanked us for the partnership and wrote, “You’ve opened my eyes again of why I became a teacher.” Lastly, Laura leveraged her school’s proximity to the university, and the research team has continued to work with her on her biology course, a new course she designed for scientific research, national conference presentations, and a recently funded grant to support connecting students and university scientists at her school.

Relationship building between researchers and practitioners is key to supporting sustained implementation and collaboration in schools with highly variable contexts, commitments, stances on teaching and learning, and support systems (Linn, Shear, Bell & Slotta, 1999). This is especially true—and more challenging—when done at a distance. While much of the success of the year could be attributed to the personalities of the teachers and researchers, which included significant work by everyone involved, there are key features of the co-design that can also help to explain how this played out. The face-to-face meetings afforded in-person community building but also new experience and opportunities for teachers to be in professional environments as members of a design partnership. Second, our stance on learning and teaching emphasized that all students and teachers are capable of rigorous and relevant work, which was represented in the design principles of the project. Finally, three graduate students and a few staff members were available on the phone or by email every day of the week to support teachers, answer questions, locate materials, recommend adaptations, or just to talk through instructional planning. In the first year of full implementation of an ambitious, technology-supported, contemporary science curriculum, all three of these PD aspects were necessary for ensuring successful experiences for students. These strategies allowed for the different kinds of knowledge that individuals held to contribute to the effort as a result of the strong collaboration.

This reflects a central tenet of DBIR—that both researcher and practitioner knowledge and human capital get leveraged as people encounter new problems associated with scaling. For example, the research team could stop and map the curriculum to the state standards because we knew the curriculum and we had the *time* to do that kind of work. The teachers could then use that product as part of their internal conversations with administrations. That is crucial also for implementation at scale. In another example with both knowledge and capital dimensions, teachers knew we were analyzing student assessment data for internal report, and teachers could ask us for school-level analyses to use as a tool for sharing their student outcomes with their districts.

Future research could examine teachers' identity shifts over the course of a school year when they are engaged in design partnerships around innovative and complex curricula. One way to look at this would be to analyze how they talk about a shift in their own position within a school or district setting and how their talk about students does or does not shift students' positioning as capable learners and developing experts throughout the course of the year. These teachers all had been teaching for more than 11 years—and in some cases 30. They were each in unique positions as teachers within their schools or larger networks to pursue strategies for long-lasting change and sustained improvement in students' learning experiences. They each played a role in the capacity building efforts of the schools.

### **Discussion**

The variations in dilemmas that arose when teachers in different contexts implemented a new intervention demonstrate the need for designers to anticipate the ways in which teachers will respond to and manage dilemmas as they arise. Some dilemmas provide disturbances to the system that lead to outcomes that could not have been achieved without the intervention. Other

dilemmas create challenges that are difficult to resolve. By anticipating the ways in which teachers manage dilemmas, designers can attempt to eliminate those that are unproductive (e.g., the need to coordinate between multiple technology platforms) and develop resources to support teachers in managing those that are necessary or productive (e.g., standards alignment documents). This study begins to provide designers insights into the types of situations in which people with less history and support can get help in implementing new interventions through a co-design process.

It also points to the ways in which co-design can help teachers with variable histories and access to resources manage dilemmas of implementation. Sustaining management of dilemmas across an extended implementation effort can be supported through relationship building and co-design that focuses on managing dilemmas that are high-leverage for student engagement.

### **Design Implications for Teacher and Researcher Co-Design Collaborations**

This work provides design implications for co-design collaborations focused on supporting teachers at a distance to implement innovative ambitious curriculum that engages students with the contemporary problems and techniques of modern biology. First, design collaborations benefit from relationship building through joint engagement in the work. This collaborative stance matters for productive talk between teachers and researchers, especially in online meetings. It also allows for frank discussions and openness to sharing dilemmas, struggles and successes, which developed into a shared context of each teacher's school contexts and cultures. Second, just-in-time supports for teachers are necessary for teachers from all school types during their first enactment of the intervention. A new curriculum with many complex features (e.g., materials for investigations, use of an online platform) naturally brings up questions about coordinating pieces in the day-to-day instructional practices. Just-in-time support allows teachers

to focus on creating the highest quality learning environment in their context because the research team had devoted time to answering questions or developing resources. Simply, the research team had developed the materials and therefore had a history and level of expertise to share with the teachers. Third, this collaboration and support should happen through co-design arrangements that place teachers in expert roles to make curriculum decisions important to their local contexts. Positioning teachers as experts in their instructional contexts means supporting them to make productive adaptations of the curriculum that address a current need. It also allows teachers to share their expertise and instructional strategies for managing dilemmas in implementing a new intervention. Fourth, important insights for learning and scaling arise when teachers have support to communicate and understand each other's local contexts. Collaboration of teachers across contexts can be valuable to the research endeavor since we have very few instances of teacher partnerships across time and location. Finally, a co-design collaborative stance in teacher support and implementation work counters the perspective that researchers do work disconnected from actual details of practice. The researcher stance in the work and the willingness to document and engage with the details of practice across contexts allows for design-based implementation research to make meaningful contributions in theory and practice.

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### Chapter 3: Epistemic Practices In Contemporary Science Investigations

The *Framework for K-12 Science Education* (NRC, 2012) calls for the focus on science and engineering education to be learning in practice. The release and subsequent state-level adoption of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) bring forth to need to understand how all youth learn through engagement in epistemic practices — the scientific practices of knowledge building. What types learning environments support learning in practice? What resources do students need to support their engagement in practice-focus instruction? What complications and synergies result from engaging students in epistemic practices? There are eight epistemic practices of science and engineering defined in the *Framework*:

1. Asking questions (science) and defining problems (engineering),
2. Developing and using models,
3. Planning and carrying out investigations,
4. Analyzing and interpreting data,
5. Using mathematics, information and computer technology, and computational thinking,
6. Constructing explanations (science) and designing solutions (engineering),
7. Engaging in argument from evidence, and
8. Obtaining, evaluating, and communicating information.

In this study, three practices receive the most attention due to the specific curriculum design under investigation: planning and carrying out investigations; obtaining, evaluating, and communicating information, and engaging in argument from evidence. The NGSS (NGSS Lead States, 2013) appendix F articulates hypotheses about how performances of practices build on each other across grade bands ending in expected practice performances for high school. I make

use of these statements along with specific curricular elements to articulate how the scientific practices are expected to play out in this study. The following paragraphs summarize these expected practice performances.

First, when planning and carrying out investigations students should evaluate the investigation's design to ensure it will be able to help answer the scientific question (NRC, 2012). They should also select appropriate tools and reflect on the appropriate use of tools in relation to the evidence they are trying to gather through the investigation. Finally, investigative plans should include consideration of the study's impact on environmental, social, and personal issues.

Obtaining, evaluating and communicating information (the information practice) asks students to evaluate information and summarize and communicate ideas. It is important to note that the information practice occurs throughout the investigative process not just as a culminating activity at the conclusion of an investigation or unit. When evaluating information, students should compare multiple sources from varying media types to address a scientific question or to inform another practice, such as, investigation design. From this information, students should summarize ideas by noting the central ideas in a text. Finally, when communicating ideas students should produce writing or presentations to clearly demonstrate their scientific work.

Students' engaging in argument from evidence in PBL environments asks them to make claims about the natural world using evidence they gathered supported by other scientific knowledge. Complex claims should be defended with evidence, and reasoning in the argumentative product, the written component of the argumentation learning progression proposed by Berland and McNeill (2010).

This shift to focus on epistemic practices in science education broadens access to

participation in science practices in the classroom, which increases students' chances of both STEM careers and productive use of science in their everyday lives. Broad inequities in science achievement exist for youth from non-dominant communities. And yet, all youth should be able to use science and scientific thinking in their everyday lives and, if they choose, in pursuit of science, technology, engineering, and mathematics (STEM) careers. Sociodemographic diversity in the STEM fields do not mirror the diversity of our society—although there is significant evidence that broadening participation in STEM fields will improve the scientific knowledge that is produced (NSF, 2008). There are broad-scale challenges associated with improving opportunities to learn science for all youth, especially those coming from non-dominant communities who frequently face more remedial and conservative forms of pedagogy.

In learning environments, specifically schools, this means promoting powerful, inclusive science learning experiences for youth. Sociocultural and sociocognitive theories of learning (Vygotsky, 1986; NRC, 2000) have identified educational design principles that can be productively used to cultivate powerful learning environments. Relatedly, the social practice theory view of learning within and across situations has become increasingly leveraged over the past two decades (Lave, 1988). Social practice theory is relevant to the goal of broadening participation by engaging youth in more professional forms of scientific practices given its theoretical focus on engaging students in practice and studying identification. This will continue to gain relevance as implementation of the Framework vision with a focus on the practices and identification occurs across formal learning environments. We know from this research that all significant learning involves identification processes as people come to participate in social practices (Lave & Wenger, 1991). This knowledge about qualities of learning environments was leveraged in our consensus accounts of science learning and teaching and the new vision for K-

12 science education (NRC, 2007, 2009 & 2012).

This perspective on learning—often referred to as “the practice turn” in science studies and “social practice theory” in the learning sciences—foregrounds how people come to engage in scientific practices. Powerful learning environments build upon prior interest and identity and focus on the continued development of these strands of learning in relation to conceptual and epistemic knowledge development as youth participate in disciplinary practices. However, we lack educational design knowledge about how to engage in identity-centered design of learning environments, especially within the context of formal schooling in which the institutional culture can make it more difficult to accomplish. Taking the practice turn in science education will allow students to identify with science in more meaningful ways as they learn through engagement in disciplinary practices. This work also contributes to the emerging educational research and development agenda around coordinating learning across the settings of youths’ lives by exploring the ways in which the design of learning environment can leverage students’ outside-of-school interests and expertise (Bell, Bell, Bricker, Reeve, Zimmerman, Tzou, 2012).

The Developing Meaningful Expertise Instructional Framework takes into account that participants in the learning environment must coordinate these multiple bundles of social practices (Bell, et al., 2012; Bell, in preparation). Used as an instructional design framework, the Developing Meaningful Expertise Framework builds upon the Cultural Learning Pathways learning framework to inform the design of learning experiences for youth that “deepen their participation in a practice amidst a myriad, and often competing, set of different systems of competency” (Bell, et al., 2012). The central aims of this design framework and hence the analysis and argument development in this paper are: (a) deepening participation in disciplinary practices, (b) promoting meaningful engagement, (c) supporting learner agency, and (d)

facilitating metacognition (Bell, in preparation). Each of these are intertwined in the youth's engagement in the investigations and require close attention to the ways in which the epistemic practices of the sciences are (or are not) coordinated across the social practices of youth.

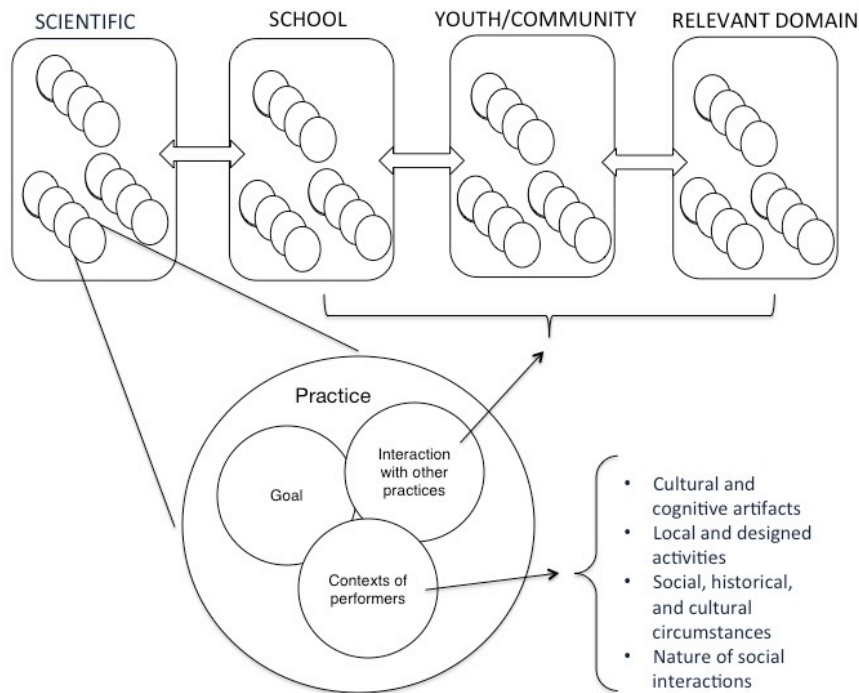
The rationale for this study is to learn how to productively and deeply engage students in the epistemic practices of science, framed by *The Framework for K-12 Science Education* (NRC, 2012) through building on the history of relevant work in the learning sciences and science education. This work is grounded in the exploration a specific project-based learning (PBL) instructional model.

### **Theoretical Framework**

The present work takes practices to be collective actions that exist within a nexus of contexts that people and artifacts travel across, and they are affected by the instructional and historical natures of those contexts. Practices have social norms, evaluative criteria, cognitive tools, and supportive resources and are interconnected in localized networks that change and are altered by participants over time. Dreier's theory of social practices situates practices in the complex interactions of people in the social world, across the contexts of their lives. Dreier (2009) advocates for a switch in psychology practice from treating people as subjects to treating people as participants. People live and participate in multiple diverse contexts and these contexts are socially and materially arranged to allow for particular practices to occur within them, together the contexts are separated or linked from other practices in a "comprehensive structural nexus of social practice" (Dreier, 2009, p. 196). The framework developed here based on this view acknowledges that students' contexts of practices are situated within four sets of partially aligned and sometimes competing bundles of social practice present in the learning environment: (a) contemporary professional scientific practices (e.g., planning and conducting a scientific

investigation); (b) school practices (e.g., participating in mandated, orchestrated assessments); (c) youth and community practices (e.g., the daily practices of the youth and/or local community); and (d) the practices of relevant social domains (e.g., societal arenas with established sets of practices).

The epistemic practices of science and engineering have been given special status and definitions especially with the practice turn in science education and the release of the practice-focused NGSS, I take the opportunity to explore what we mean when we say scientific practices within (or in connection to) the Developing Meaningful Expertise framework and use social practice theory as framework for studying student participation, learning, and opportunities for identity development moments through scientific practice-focused learning experiences. Scholars across disciplines have been working for decades conceptualize practices specifically the practices associated with the knowledge work in the sciences. Theoretical views from science and technology studies provide a focus on how science happens in practice and how scientific practices result, often through messy trajectories, in scientific knowledge. With a focus on the STS literature that documents the practices of science from a sociomaterial perspective, I will leverage the definition of practices Rouse (1996) puts forth: scientific practices that groups engage in are not “the doings of human agents but... the meaningful situations within which those doings can be significant” (p. 38). These situations or configurations have specific features that allow them to be documented as practices. According to Rouse (2007), normative practices have three key features: (a) they are bounded by the ways in which performances of practice interact; (b) there is something “at issue” and “at stake” in the outcome of the practice; and (c) performances of practice are situated in the circumstances of the performers.



*Figure 1.* General configurations and influencers of social practices.

My framework approaches practices as “patterns of activity in response to a situation. Practices are dynamic because these patterns exist only through being continually reproduced. Their coherence and continuity thus depend both on coordination among multiple participants and things and on the maintenance of that coordination over time” (Rouse, 1996, p. 26). Knowledge is foregrounded in social and material practices. Lynch writes, “...we should forget ‘knowledge’ as an adequate way of formulating the entire ‘content’ of a science. Much of what goes under the heading of ‘knowledge’ in science studies can be decomposed into embodied practices of handling instruments, making experiments work, and presenting arguments in texts or demonstrations” (Lynch, 1997, p. 310, emphasis added). I argue students’ gain an understanding of the important social and material aspects of scientific work through participation in and continual reproduction and refinement of the embodied practices of the disciplines.

Science understanding should also centrally grow out of the lived experiences of learners (Calabrese Barton & Tan, 2010; Bell, et al., 2012; Gútiérrez & Rogoff, 2003; NRC, 2007, 2009). This means supporting learner choice and allowing for meaningful connections that are personally relevant and related to community interests. In addition, through instruction, experience with materials and scientific tools, and access to disciplinary experts, youth are positioned as developing experts (Bricker & Bell, 2012; Harré, 2008) in relation to a set of disciplinary practices, core ideas, and crosscutting concepts. The teachers and disciplinary experts support the students in more deeply engaging in the science practices over time. Youth are also encouraged to leverage their expertise of epistemic practices as they engage in the science practices.

To understand learning as sociocultural is to see learning as something that happens in practice. In this framework, I leverage Nasir & Cooks (2009) definition of learning: “shifts in the use of artifacts (both cultural and cognitive) for problem-solving, sense-making, or performance” (p. 44) to locate learning as a traceable entity in practice. Rouse (1996) also argues for science to be understood through practices instead of through set scientific knowledge. His account of practice stems from his definition of scientific knowledge and the location of said knowledge. In typical accounts of scientific knowledge, agency is located in the knowers and practices are what knowers do. For Rouse (1996), practices are configurations of the world in which the activities of agents occur and knowledge is a description of the situation a knower is located in and knowledge is not something that person acquires (p. 133). A practice is both a setting of action and the action itself and scientific knowledge is located within these practices. It is located in the ways that practices come together to make sense. Rouse (1996) writes:

A typical practice needs other practices to enforce its norms, provide it necessary equipment and resources, educate and train its practitioners, confer significance on it or undercut the previous significance, conflict with its continued development in any of the foregoing ways, and in general, help configure the world in ways that allow the practice to be intelligible. (p. 156)

Science is a set of linked practices (NRC, 2012; Latour, 1987, Pickering, 1995). Scientific practices, as a subset of social practices, are socially organized in comprehensible and comprehensive ways. The links and separations between the scientific practices are what structure the nexus of practices and make it traceable to actors (Rouse, 1996; Dreier, 2009). These linked practices are mutually dependent and they are defined in relation to one another and therefore should not be considered isolable (Pickering, 1995; Penuel, in press). The Framework promotes learning science in practice but this idea of linked, non-isolable practices has to be teased out and designed for.

I take learning in practice to be the individual and group-level shifts in the use of cultural and cognitive artifacts to solve science-related problems, make sense of scientific issues, or perform scientific work. Proficiency in scientific practices comes from and is demonstrated by these productive shifts and the performance of patterns of practice over time.

This analysis addresses the research question: How does a project-based curriculum model that engages students in contemporary scientific problems support students' participation in disciplinary epistemic practices and conceptual learning? This question relates to many conceptual dimensions of student learning in the context of teacher practice. The context of the study is a classroom for which participation in epistemic practices is novel and challenges notions of what it means to learn science. Documenting student pre to post conceptual learning is

necessary to provide the context and to argue for rigorous engaging learning experiences. Project-based documents are group-constructed written documents and writing is a social activity situated in the historical moments, contexts of the writers, and their interdisciplinary concerns (Bazerman, 1998). In this study, writers (students) are situated within the context of school, which comes with a set of practices that are linked and separated from the contemporary scientific work they are asked to engage in in the classroom. Efforts were made in the instructional design to allow students to leverage and focus on community practices or personal interests as a way to promote relevance in learning. Taken together, these various dimensions highlight the conceptual space of analysis for this paper using the following methods and data sources.

### **Methods and Data**

This study is design-based research (Brown, 1992; Design-Based Research Collective, 2003) analyzing one project-based unit that is part of the year-long introductory Biology course. The educational intervention consists of a year-long introductory Biology course composed of five project-based instructional units delivered on a social media technology platform. The curriculum approach sought to engage students in contemporary science focused PBL projects that were structured to give students space to take on interest-driven investigations. The curricular materials were delivered on an online platform that also served as a place for students to conduct discussions, learn about each others' interests, save notes and brainstorms, and interact with disciplinary professionals. These disciplinary experts were tapped because of expertise and careers topically related to the unit and they interacted with students on the online platforms to give them feedback on their project work, answer questions related to the topics under study or their field and career, and to act as an audience for students' culminating

products. Across the five curriculum units, students participated in investigations that spanned across types of scientific work and included fieldwork, bench work and computational work.

During the beginning stages of course development (2010-2012), units were piloted individually in a collaborative co-teaching model with researchers present in the classroom each day. This analysis focused on an initial pilot use of a DNA barcoding project that lies within the eight-week long genetics unit. The analysis consists of quantitative analysis of pre- and post-test scores and student-reported engagement data, an analysis of practices over the course of the unit, and analysis of student works across the overlapping cascade of practices that unfolds in the unit (Bell, et al., 2012). The data includes the full Spring 2012 data corpus for this unit enactment which includes: student work and class performance data (n=71), student artifacts from 12 groups (which included 4 students per group), instructional records (lesson plans and daily reflections), one student focus group, and interviews with four students and one teacher.

This enactment of the unit took place with five biology classes taught by one teacher in a public, urban high school in the Pacific Northwest. The school houses a biotechnology academy, however, the introductory biology classes were not part of the academy. The teacher, Mr. Lewis (pseudonym), was a first-year teacher who completed his student teaching in a biology/AP biology classroom. Seventy-five students participated in the study across the five biology classes. The unit included a mix of traditional high school biology content (e.g., properties of DNA, molecular basis of inheritance, cell replication processes, etc.), non-traditional laboratories (e.g., *Drosophila* breeding), and a project focused on contemporary issues and techniques—the DNA Barcoding project. During the unit, students planned and carried out a species identification research project of their choice using a technique called DNA barcoding. This technique used by scientists to collect DNA sequences and identify the species. Using the results from this process,

scientists are adding to a database designed to capture the biodiversity of life—making it accessible to scientists and the public. In the DNA Barcoding project, student wrote a research design plan, received feedback from experts and educators on the plan, collected samples, used wet laboratory techniques to extract the DNA from the samples, sent the samples to a company for sequencing, and then analyzed the resulting sequences using the online tool BLAST (<http://blast.ncbi.nlm.nih.gov/>) or the Barcode of Life (<http://www.barcodinglife.com/>) nucleotide sequence databases. In these projects, student groups choose and investigated species identification questions, such as: What other organisms can be DNA barcoded from imitation crabmeat and how harmful can they be? and Are there ingredients in natural cough drops that are not listed on the package?

The project was designed so that students were engaged in several scientific practices that were mutually dependent on each other: (a) Planning and carrying out investigations; (b) Obtaining, evaluating, and communicating information; (c) Asking scientific questions; (d) Analyzing and interpreting data; and (e) Argument from evidence. In addition, in groups students were supported to brainstorm and choose a species identification problem of their choice that was important to their own or their community practices. For example, many groups choose to investigate the meat being served in the cafeteria. The following analyses investigate various levels of students' engagement in these practices.

### **Analysis and Findings**

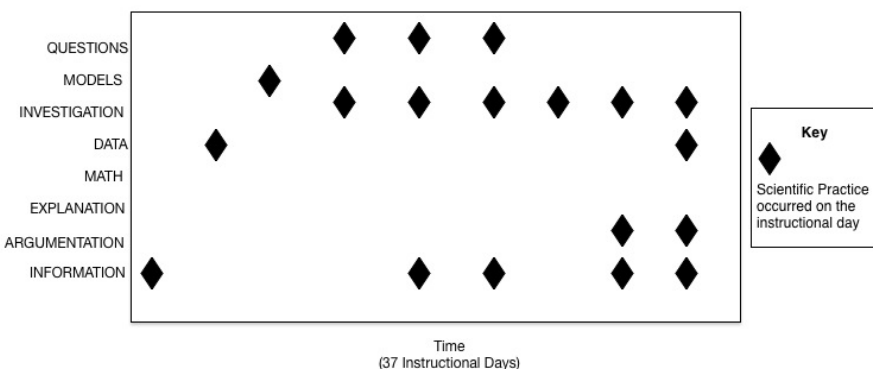
The study employs retrospective methods (Gravemeijer & Cobb, 2006) to analyze data collected during the design-based research. Four analyses are reported as part of this mixed-methods study. First, a statistical analysis of students' conceptual learning on pre- and post-test scores and reported-levels of engagement along five dimensions (Newman, 2005) is presented. Then, two

case studies that demonstrate how two different groups proceeded through the DNA barcoding investigation are analyzed. Next, a document analysis a analysis of the scientific practices, youth practices, school practices, and relevant social domain practices as they interacted in two time points of student groups' written documentation: research design plans for the investigation and proposals for continued funding of the DNA barcoding project. Finally, with both time points of student work taken together, I analyze how students' argumentation for continued funding is aligned with their investigative practices. To set the stage, I describe the practice-focused instructional approach and how it was present in the curricular materials.

### **Curriculum Design Analysis – Timeline of Practices**

The adoption of the scientific method into science curricula across K-12 has created a false sense of linearity, homogeneity and certainty in science learning experiences for youth. In this analysis, I look at how student engagement in the epistemic practices occurred throughout eight-weeks of curriculum with a contemporary project-based learning approach. This practice-focused instructional approach takes students through a more scientifically authentic cascade of practices: Asking a scientific question, planning and carrying out an investigation, analyzing and interpreting data, asking another question, and culminating in the writing of an argument that proposes a plan for a subsequent investigation (via a proposal for funding). The instructional design stance assumes there are many ways to flow across engagement in the practices in order to conduct an investigation. The timeline in Figure 2 shows a mapping of the flow of scientific practices for each day of this curricular enactment. The figure demonstrates how the practices overlapped and repeated over the course of the enactment but the analysis is not able to show how students engaged in work of the practices and if they did so as intended. After the initial

round of coding, I chose five days of the 37 instructional days in which the practices were not initially coded and reviewed those five days for student engagement in practices.



*Figure 2.* Distribution of scientific practices over time in DNA barcoding unit curricular materials.

Emerging from the map of scientific practices across 37 instructional days is the pattern of the cascades of practices that can play out when practice-focus instruction is foregrounded in a learning environment. Practices often occurred on the same days as each other, except when the Planning and Carrying Out Investigations practice stands alone for six instructional days. This is due to the intense laboratory work needed to carry out the DNA barcoding investigation. The obtaining, evaluating, and communicating information practice (Information) occurs throughout the instructional sequence instead of being confined to the traditional role of students “reporting out” at the end of a unit. For coding purposes, the information practice specifically tied to information gained from an outside source or a statement communicating about the investigation while argumentation was coded as statements persuasive goals or intents. This is an important feature of the Information practice, and research has documented that over half of the work of scientists and engineers takes the form of interpreting and generating text (NRC, 2012; Tenopir and King, 2004). It is also important to note that this practice often occurs with other scientific practices. The Developing Meaning Expertise instructional approach works from the assumption

that learners engage in an overlapping sequence of primary practices, with adequate epistemic alignment that requires practices to be mutually dependent in order to accomplish the aims of the investigation, and that secondary practices are invoked at specific points in which they support the work of a primary practice. Students need to obtain and evaluate information in order to ask relevant and testable scientific questions, to develop models, and to plan and carry out an investigation. In this representation, we see links between scientific practices that are to be expected given the complexity of authentic scientific work.

This curricular practices analysis highlights the need to dig deeper into student participation in these practices. Their appearance in the instructional materials does not equate to rigorous student participation in the scientific practices. In addition, analysis of student work allows for culling instances of contextual cues that support and hinder students' meaningful participation in the scientific practices.

### **Conceptual and Engagement Analysis**

We developed and administered pre- and post-tests to students that included conceptual assessment questions for concepts that relate to the learning goals in the *Framework* as well as the Washington State Biology End of Course exam (which students need to pass to graduate high school in Washington state). The focus of the assessment was conceptual and it spanned two *Framework* Core ideas: HS-LS3 Heredity: Inheritance and Variation of Traits and HS-LS1 From Molecules to Organisms: Structure and Processes. Figure 3 demonstrates the assessment alignment with the core ideas as well as the percentages correct on the pre (N=72 students) and the post (N=69 students).

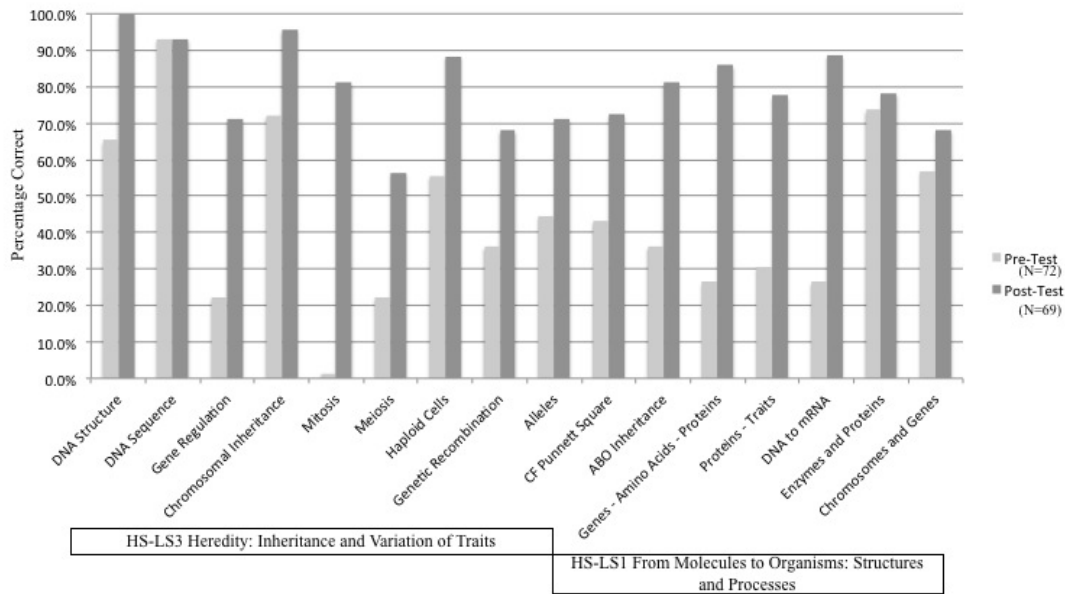


Figure 3. Representation of student pre- and post-assessment data.

Questions included multiple-choice, short answer, and true/false response options and covered ideas such as the regulation of gene expression, the events that occur during protein synthesis and how alleles are contributed to gametes.

**Test assessment of student conceptual learning.** Overall, students made variable, positive gains from pre- to post-test on all scored items. As a measure of conceptual learning of specific content, a t-test of aggregate pre- and post-test scores revealed differences in pre-test and post-test scores before grouping by class,  $t(131.86) = 15.24, p < 0.001$ . It seems that the content-intensive unit activities and the project investigation enabled students to work in-depth with the concepts and phenomena represented by this content. Students were not very familiar with science content previously, and researchers worked with the teacher to focus many hours of instructional time on helping students learn these scientific concepts. A one-way ANCOVA was conducted to see if classes differed on post-test score when controlling for pre-test. This indicated a main effect of pretest on post-test outcomes was significant,  $F(1, 1) = 13.33, p < .001$ . However, the main effect of period (i.e., which class period students were in) was not significant,

$F(1,4) = .767, p > .05$  OR  $p = .551$ . Since classes did not differ in outcome when controlling for effect of pre-test, we used collapsed scores across all classes for linear regression analysis.

**Survey assessment of student engagement.** In addition to conceptual learning, a tenet of the overall course design was that high learner engagement in cultivated learning environments will support their deeper learning. The design intent being to make these courses very compelling and engaging to students through the use of various project-based learning and culturally responsive instructional strategies that included a contemporary science focus, extended project work, student choice in investigation, and investigative techniques that can be leveraged for community and personally relevant investigations. This goal stems from the student-identified issue that school science and school more generally do not address topics and areas of study that are directly relevant to students' lives. Measuring engagement using repeating surveys was important to track students' reported engagement in the storyline of the course alongside the rigor assessment moments.

To measure student engagement in the course we created an online survey adapted from the FUN Unification Model (Newman, 2005). We asked students to respond to six questions during three time points in the course: (a) after the first week of the unit; (b) after the third week of the unit, which was when students were introduced to the DNA barcoding project; and (c) during the last week of the unit and the final phases of the project work (e.g. data analysis and writing proposals for funding). On the survey, students indicated their engagement using a Likert Scale (one being strongly disagree and five being strongly agree). Each question on the survey mapped one of the five engagement constructs in the FUN unification model: (a) Temporal Disassociation, *Time seemed to go by very quickly while I was working on the genetics unit this week;* (b) Focused Immersion, *I was absorbed in what I was doing while I worked on these*

activities; (c) Heightened Enjoyment, *I have had fun working on the genetics activities this week; The interaction with other people (peers and educators) was very enjoyable*; (d) Narrative Engagement, *I was able to participate in and contribute to our study of genetics*; and (e) Intention to Revisit, *I would like to learn more about genetics*. We analyzed engagement over time to inform curriculum design, especially at time points where students reported low levels of engagement. Figure 4 shows the three times points we measured engagement during the unit enactment.

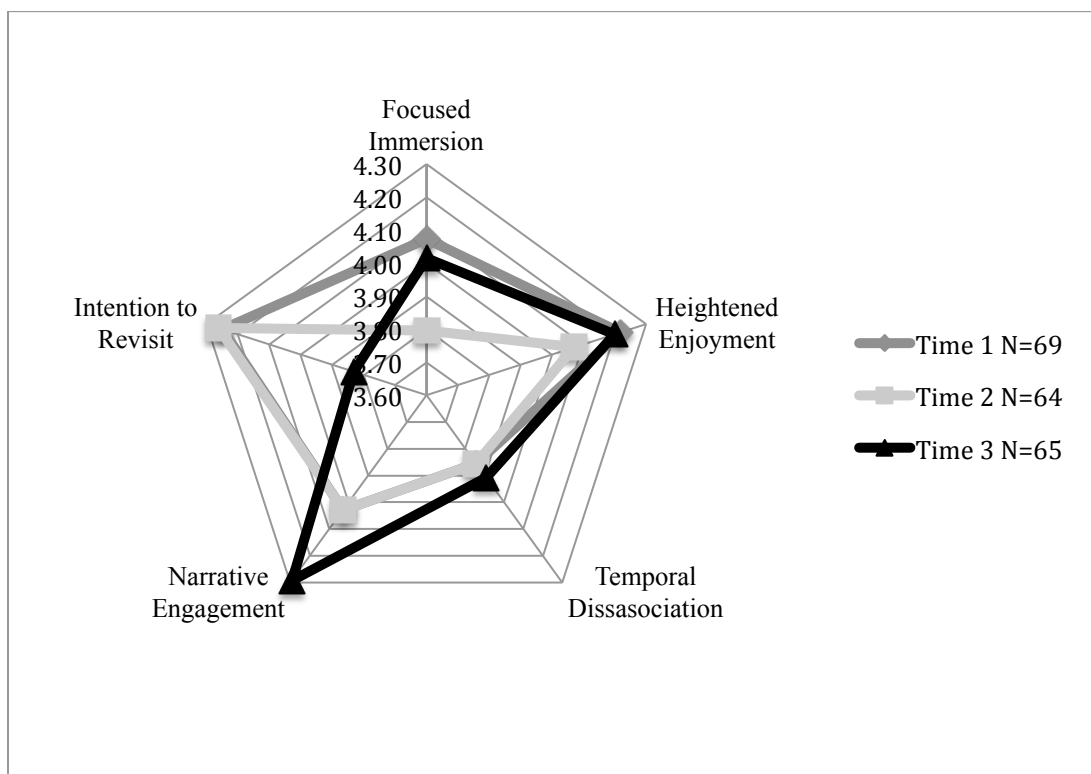


Figure 4. Engagement dynamics at three time points in the genetics unit.

Students reported greater than neutral engagement across all five dimensions throughout the unit. Students' reported engagement varied by construct across Time 1, Time 2, and Time 3. Students reported being most absorbed (Focused Immersion) in what they were working on at Time 1. Students also reported having fun and enjoyment working with peers and educators (Heightened Enjoyment) at Time 1. This may be due to the introduction of the laptops to the

classroom at that time and the additional three researchers in the classroom. Across the unit, students seemed to enjoy having extra adults in the classroom. There were always students eating lunch with us and discussing sports and science class. At Time 1 and Time 2, students reported being most interested in learning more about genetics (Intention to Revisit). This occurred as the unit began and then again as students started working on their projects. At Time 3 students reported highest engagement related to their participation in the study of genetics, specifically DNA barcoding (Narrative Engagement) and the perceived quick passage of time during this part of the unit (Temporal Disassociation). During this portion of the unit, students had just completed three days of lab work to analyze their samples and they began to analyze data. Students were all participating in the work and much of the project activity was packed into the last two weeks of the unit. Students indicated their engagement using a Likert Scale (1 being least engaged and 5 being the most engaged). Although student engagement varied between time points with respect to the various dimensions of engagement it should be noted that at no time did average student engagement fall below 3.8 (well above neutral) on any dimension of engagement across the three data points. Next, I used regression analysis to examine if there was a connection between engagement and performance on the post-test.

**Relating student engagement to final conceptual understanding.** Engagement values for each student were calculated by determining an average engagement score by construct across the three time points. Then in order to determine if variance in the post-test scores could be accounted for by the engagement constructs a stepwise linear regression was conducted on the average post-test scores first accounting for variance from pre-test (block 1) and then block 2 included each of the engagement constructs.

Of the engagement constructs many were significant but did not explain a large amount of variance. Focused Immersion (FI) was significant,  $r=.30$ ,  $p<.01$ . This indicates that 9% of the variance in the post-test was accounted for by FI engagement. Immersion in the unit and project work supported some of what students conceptually understood at the end of the project. Heighten Enjoyment (HE) was also significant,  $r=.20$ ,  $p<.05$ , indicating that 4% of the post-test was accounted for by HE engagement. Thinking the unit was fun over time supported understanding at the end of the unit. Narrative Engagement (NE) was also significant,  $r=.32$ ,  $p<.01$ , indicating about 10% of the post-test variance was accounted for by NE engagement. Making connections to the storyline of the unit supported students' conceptual knowledge. Similarly, Intention to Revisit (IR) was significant,  $r=.28$ ,  $p<.05$ , indicating approximately 8% of variance was accounted for by IR engagement. Desire to continue to delve into genetics content also supported some of students' conceptual understanding. Finally, Temporal Disassociation was not significant,  $p>.05$ .

Together this regression analysis is consistent with what was expected given design strategy that engagement and academic rigor can occur simultaneously in a learning environment and engagement may, in fact, account for student's performance on the final conceptual assessment. Fieldnotes of daily classroom observations noted consistent student engagement across the course. We recognized observed engagement as on-task behavior and student comments to the educator team about their interest, enjoyment, and affect related to course activities. This analysis is also consistent with student responses to questions about what they liked about the unit. One student wrote, "It was interesting to learn how every cell billions of cells in every living thing have their own sequence of DNA." Reflecting on his participation in the project and growth over the course, another student wrote, "I really enjoyed being able to

actually extract and barcode DNA, which is something I never thought I would actually get to do. I also learned a lot about genetics, a field in which I hardly knew anything prior to the unit.” The case studies will go into more depth on these engagement dynamics and students’ interaction patterns and reactions to the investigative work and the unit overall.

Finally, I regressed the engagement constructs against a learning gain score (i.e., the pre-test subtracted from the post-test) and found no significant correlations. This indicates that engagement does not predict course conceptual learning in the unit. Combined with above results this can be taken as a reminder that learner engagement and conceptual learning are related but that students who engage may have higher post-test scores, or higher achieving students may simply be more engaged by this kind of unit.

Students gained conceptual understanding of core ideas related to heredity and structure and function during this instructional unit. Their immersion, narrative buy-in, reported fun, and desire to continue studying genetics may have contributed to the post-test scores. Rigorous conceptual learning as is measured by culminating assessments can occur after students participate in a project-based unit focused on scientific practices. More design-based research needs to be done to understand how to seamlessly connect high school level core ideas with contemporary scientific projects that often require much more complex and higher-level ideas than are typically taught in an introductory level biology course.

### **Case Studies: Groups Engaged in Investigative Sequence**

Student engagement in practices involves highly multifaceted, contextual activity and affective engagement in the work varies by group member. To set the stage for further analysis of student work, a process diagram representation, a tool to document engineering and business processes, was employed as a visualization tool to understand the investigative processes of two

focal student groups. This diagram was developed through analysis of curricular materials. This affords a detailed look across time of a group of students collaborating with something “at-stake,” while using narrative analyses to show how the performances of practices interacted, and triangulating with data from student metacognitive reflections about the circumstances of the performers of the practices. I coded student responses to a metacognitive survey (modeled from the one developed by White and Fredericksen, 1998) that had been built into the curriculum that asked students to reflect on their perceptions understanding of the science, with whom they talked about the work, the inventiveness involved in the work, their use of scientific tools, and the teamwork within their group. Each prompt was related directly to students’ investigative work (e.g., My team’s research design plan and project work show that we are creative, original, and inventive in thinking about our research question, our investigation design, and the tools we are using [Sample Collection, DNA extraction, amplification, and gel electrophoresis]).

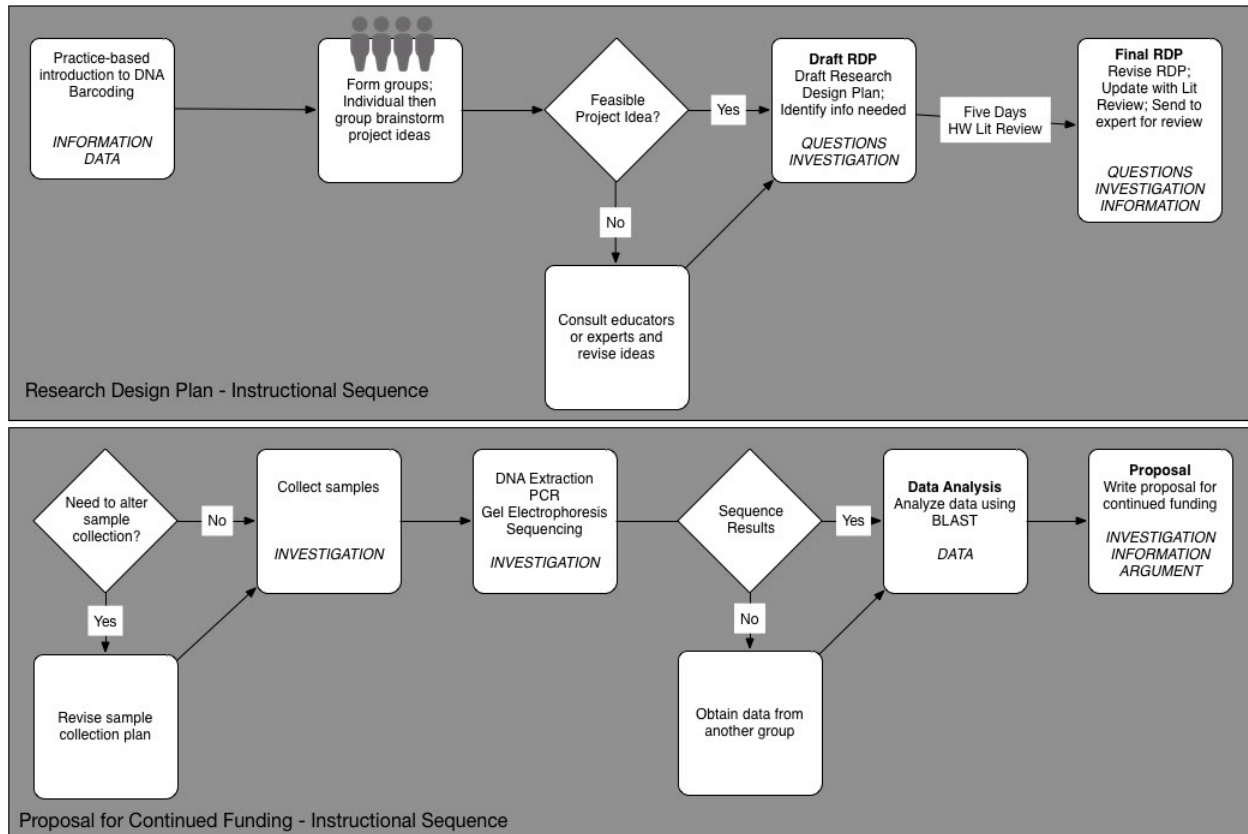


Figure 5. DNA barcoding process diagram.

The designed process diagram seen in Figure 5, demonstrates how the two major product documents involved with the investigation—the initial Research Design Plan and culminating Research Proposal for a “follow-on” study—were supported in the designed sequence, including key decision points for students and where each scientific practice shows up in the sequence, denoted in capital letters. In the diagrams depicting each of the focal groups’ processes, details are layered in, as well as, the students’ metacognitive reflections about the parts of the investigation. The instructional sequence begins with a set of activities designed to introduce pieces of a DNA barcoding investigation including extracting DNA and using online databases for analysis of DNA sequences. Next, students form groups, brainstorm project ideas, check the feasibility of their ideas and then starting planning the investigation using a template for their research design plan. Educators review the initial draft and then students have five days for a

homework asking them to draft a literature review of at least two sources related to their project. This assignment is combined with the research design plan, revised, and sent to experts for feedback.

Feedback from disciplinary experts is a key feature of the instructional model. Experts from fields of study related to DNA barcoding were prompted to give feedback to students on their research design plans. Experts and students interacted by uploading work and comments to the online platform. Experts and students were also able to read each other's profiles on the platform so they could get more information about learning and career pathways. Students really enjoyed when experts referred to their profiles when commenting on student work. Linking students with experts allowed us to help grow students' social learning networks and exposure to possible future career pathways as well as to facilitate authentic feedback and access to resources (e.g., scientific papers, specific disciplinary information) from experts to students.

This kicks off the second sequence that culminates in the writing of a proposal for continued funding in which students include an argument for why they should be given additional funds to keep working on their project. First, students collect samples and then they run a four-day series of protocols to extract, amplify and sequence the DNA from their samples. If the samples returned with a sequence, they analyze the sequence by comparing it to an online database and use that data to support their decisions for continuing the work.

The case studies that follow describe the issues at stake, the contexts of the performers and the social and material nature of interactions as students worked through the DNA barcoding investigation. One critique of school-based curricular interventions is the lack of flexibility in the schooling institution for implementing innovative and complicated learning experiences for youth. These learning opportunities have been well documented in out of school settings (Heath,

2012). A goal of these case studies is to analyze the features of contemporary science practice-focused projects in schools can allow for real complications and consequences to be encountered by students.

**Group case study: Herbal cough drop investigators.** The classroom was set up in a traditional classroom arrangement with a projector, computer and screen at the front of the room. The sides and back of the room were lined with counter space that served as both storage and lab space. Students sat in lettered groups of four, two people at each table. The seating arrangements were changed frequently using a randomized spreadsheet generated by Mr. Lewis and students looked forward to this change because by the second half of the school year, the expected new seats when a new unit started. The same process was used to make groups for the DNA barcoding project although the researchers gave input in order to have some groups with all research consented students. David, Erik, Kelly, and Jayna sat on the west side of the classroom just in front and right of the other case study group, Trevor, Allen, Austin, and Bailey. Kelly and Jayna were friends in the classroom and were both good and serious students. David, constantly asked questions during lectures or class activities and often made connections between the topic in discussion and his own life. Erik, often stayed after class to chat with the research team and was very appreciative of this different kind of learning experience — a project-based approach versus a more traditional lecture and activity approach. Mr. Lewis led all classes usually from the front of the room, two or three researchers stood on the sides of the room when Mr. Lewis led the class. We brought laptops in bins in and out of the classroom every day and students were assigned a computer they used for the entire units. Unless wet laboratories were in progress, students always had the computers in front of them. The general rule was screens must be lowered or closed when class discussions were happening.

One of the first DNA barcoding introductory activities was a common protocol in which students extract DNA from strawberries and the DNA is visible in globs. Two focal students, David and Austin, worked together on this extraction, smashing the strawberry to break apart the cells, adding a detergent solution to break the cellular membranes, filtering out the DNA in the solution from the chunks of the fruit, and precipitating the DNA using a cold rubbing alcohol. Students followed a protocol to extract the DNA from strawberries. The activity has been done with children of many ages but the high school students were engaged and excited to visualize the DNA. David and Austin took photos of the DNA precipitating in the alcohol layer in their cup. They quickly ran outside the classroom to tweet a photo of the DNA because their phones couldn't connect in the classroom. They came back in to show us the post to twitter, reading "DNA in bio swaaaaager...." seen in Figure 6.

## Tweets



Calvin Gaydoski @CalvinGaydoski  
DNA in bio swaaaaager [pic.twitter.com/...](https://pic.twitter.com/...)  
[Hide photo](#)



powered by Photobucket

[Flag this media](#)

*Figure 6.* Students tweet a photo from strawberry DNA extraction.

The use of students' digital literacies and social networks to share excitement about scientific work in the classroom was an important design principle of the curriculum model and as researchers we were thrilled to see the use of twitter to talk about science. The school did not have an explicit social media policy and this is the only example of a student posting and telling us directly about it. Later in the unit, another group of students realized that cameras on their cell phones were able to take photos through microscopes so they could then examine the output on their phone screens and share what they were seeing with others. The curriculum model afforded opportunities for connecting learning between students' places of activity (online and in person) and social practices. It is not uncommon with the prevalence of digital devices and internet connections for students to be well versed in making connections across settings. Mr. Lewis was

accepting of personal devices in the classroom, students listened to music regularly when they were working. When the use of digital devices become allowable instead of policed in the classroom, they can open up new spaces for learning.

DNA barcoding is a fairly new technique for scientists and youth have made contributions to the field of species identification through the Urban DNA barcode project. In addition, NWABR has materials for DNA barcoding techniques to be used in advanced level high school classes. In this case, DNA barcoding was the focal technique available for students as they planned and carried out a species identification investigation of their choosing. A visual process diagram in Figure 7 shows how David, Erik, Jayna, and Kelly made key decisions in their investigation, encountered complexities and barriers, and their reflections on these decisions and processes are layer into the visual. As they began to brainstorm project ideas, David, Erik, Kelly, and Jayna expressed interested in studying synthetic marijuana (Spice, K2), which was present in the news in Spring 2011 (e.g., [http://www.businessweek.com/magazine/content/11\\_26/b4234058348635.htm](http://www.businessweek.com/magazine/content/11_26/b4234058348635.htm)). They knew that the drug is made by spraying chemicals onto plants and they wanted to investigate what plants were being treated. One group member reported to the researchers that synthetic marijuana was quite easy to obtain and you can just get it at the local convenience store. Both researchers were quite excited about this idea to use DNA barcoding to investigate a relevant and timely issue affecting their lives. The group encountered an issue with bringing a drug onto school property. This was not unexpected but we had hoped the administration would approve the request to do this interesting scientific work, however, we were not allowed to bring synthetic marijuana into the classroom.

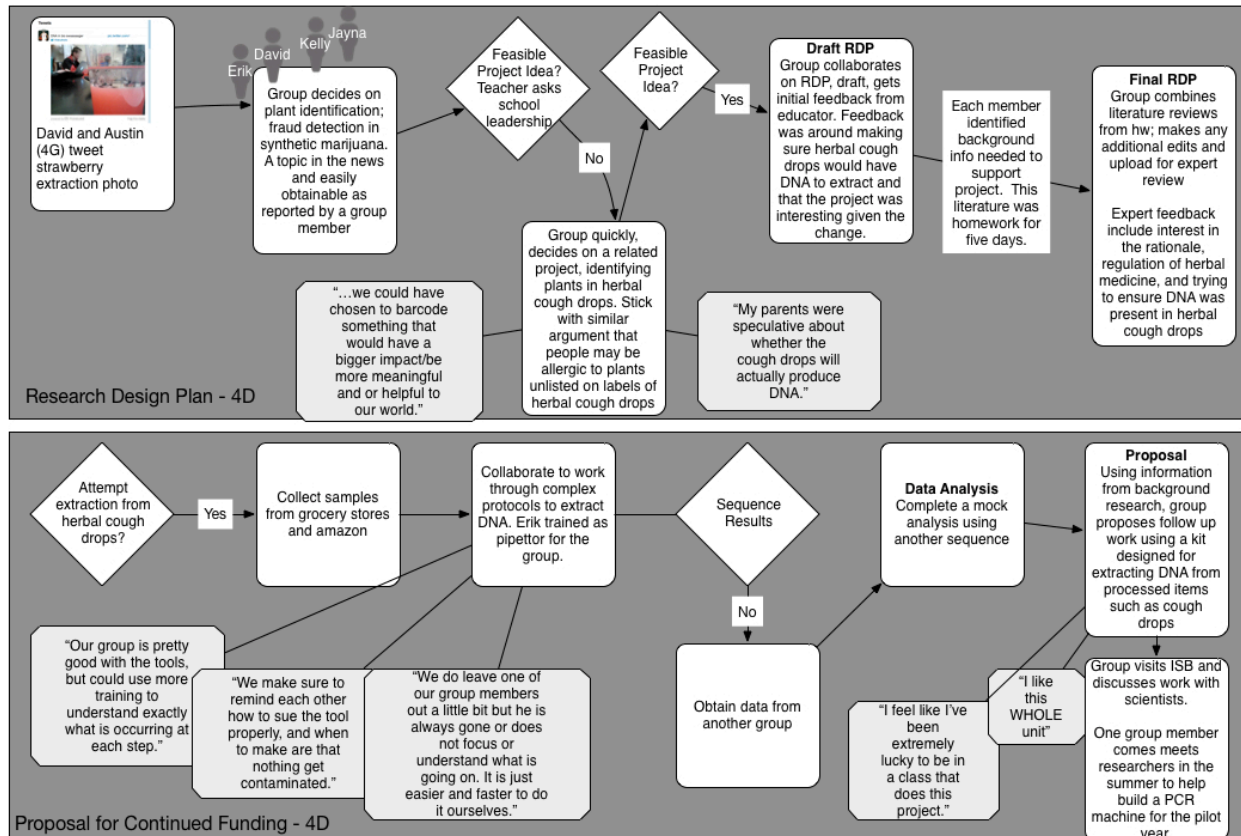


Figure 7. Process diagram for herbal cough drop investigators.

It was clear in their research design plan writing that the group felt they had to quickly change to another project idea, they wrote:

We wanted to do Spice or tobacco and find the ingredients to see if there are ingredients not listed on the label but that idea was shot down. We barely had any time to think of a new idea but we thought maybe cough drops would be a good one.

The decided to stick with the theme of misrepresented herbs in drugs by deciding to study the plants present in herbal cough drops. One educator's feedback focused on disappointment about the group not being able to pursue the project, writing, "I am actually bummed about this because I think it would have been a really interesting project. But...we have to respect the rules

so I'm glad we checked on this for you." Students also individually reflected on this decision point in their metacognitive surveys. One student reported discussing the cough drop project at home and wrote, "My parents were speculative about whether the cough drops will actually produce DNA." Another student was more concerned about the impact of the project saying, "...we could have chosen to barcode something that would have a bigger impact/be more meaningful and or helpful to our world."

Separations between using scientific practices to address contemporary science issues relevant to students and the practices of school shaped how the group's process and dynamics for planning an investigation. This initial major decision point shaped the remainder of the investigation and could have influenced individuals' levels of interest and participation in the project.

Despite the concerns of the group members (and some parents), they continued to pursue the cough drop idea and each member identified an area of needed background to research for the literature review. They identified: information about DNA barcoding, extracting DNA from cough drops, the production of herbal cough drops, and the health related uses of menthol in some herbal cough drops. In the literature review/background research portion, which students had five days of homework time to individually complete and compile as a group, they were asked to pay attention to the following instructions as they read and summarized each source:

After reading the background reading materials that you have selected, **you must write at least a paragraph about each source.** Your writing should: **(1) summarize the main ideas in the readings, (2) identify important information relative to your topic and why that information will be helpful to your group's project, and (3) discuss if the reading material raises any questions**

**for you about your group's project or argues for a certain approach.**

(Curricular Materials, Educurious, Contemporary Approaches to Genetics Unit)

After submitting the research design plan complete with four background research components to the online platform, which served to deliver curricular materials and network students with disciplinary experts to give feedback throughout the project as well as be available to share details of career and educational pathways. The expert they interacted with had extensive experience with DNA barcoding and a Ph.D. in Molecular and Cellular Biology. She gave feedback that included interest in the rationale of the study — people may be allergic to unregulated ingredients — “VERY good point. Be sure to emphasize this in your final proposal.” In addition, she said in feedback comments that the lack of regulation of herbal medicines was very interesting and she cautioned that just because cough drops were herbal did not mean there would be DNA present to extract. She also made lab technique recommendations about how much to crush up the sample for the extraction process.

Due to classroom pacing, the group had moved on to the sample collection before they reviewed the expert feedback and therefore, not much could be changed before the laboratory phase began. Erik, David, Jayna, and Kelly bought cough drops at the store and asked the researchers to help them purchase some herbal drops on Amazon.com. As the week of wet laboratories to extract DNA approached, Mr. Lewis decided to train one student in each group to serve the role as pipettor. Erik, was selected to pipette for this group and was trained on the Friday before. This position helped Erik to become the leader of the group and influenced his perceptions of science and ideas about possible futures related to science, which is discussed further in the next chapter.

On Tuesday, the most intense part of the laboratories kick off with two days of extraction in which Erik, Jayna, Kelly, and David worked through a professional extraction kit using a complex step by step protocol that require heavy use of scientific tools including pipettes, centrifuges, water baths, reagents, buffers, sterile tubes, and sterile filters. The protocol also required knowledge of the DNA extraction process to help follow where the DNA would be located through a series of washes. Erik, David, Kelly, and Jayna read through and followed the protocols efficiently with help from Mr. Lewis and the researchers in the classroom. At the end of each class period or the end of the day, Mr. Lewis would lead the researchers through finishing up where the students left off after 50 minutes if they were unable to finish the protocol. This was necessary given the sensitivity of the process and inflexibility of a school day.

In a metacognitive survey about the laboratory process, we asked students to reflect on the scientific tools they worked with and their teamwork throughout the project. One group member stated, “We make sure to remind each other how to [use] the tool properly, and when to make are that nothing get contaminated” noting the high risk of contamination in the school science laboratory and the importance of proper use of tools. Another group member had a similar reaction, “Our group is pretty good with the tools, but could use more training to understand exactly what is occurring at each step.” This was a statement that came from a few students , at times due to the rushed nature of 50 minute periods, students had to work through steps without always knowing what was happening during the step. This happened because of a combination of short class periods that did not allow time to stop the procedure to discuss each step as well as the fact that students were working through it for the first time alone in groups. In a scientific laboratory, students and professors would have had much more extensive training and practice with techniques and tools before running this protocol. In addition, 25% of students

reflected that they used the tools appropriately and effectively by following the protocol, which indicates the connection between use of scientific tools and their use for specific purposes.

Mr. Lewis ran the PCR for each sample after school because the machine took a few hours to run and was located away from his classroom in the biotechnology portion of the high school. He opted to talk with students about the PCR process given time and space limits to the machine and process. In the next class period, the pipettor from each group, in this case, Erik, loaded the samples into the gels for gel electrophoresis and we set it to run. After the gels finished, Mr. Lewis began the staining process so students could read them the following day.

When the group arrived the next day to look at their samples run through the gel, they noticed that they did not have DNA bands on the gel indicating the presence of DNA and therefore we did not send their samples out for sequencing. About 20% of all samples from all five class periods were sent out for sequencing. The following Monday we received sequence data back electronically that could be compared to the BLAST database of sequences to see if they matched with species in the database. Erik, David, Jayna, and Kelly began the class by analyzing DNA sequences from another group because we wanted all students to experience this phase of the work to gain more experience with the BLAST database tool.

In addition to the Cough Drop Investigators, many other groups did not get usable sequence data back from the sequencing company due to either contamination of the sample, inappropriate sequencing primers, or lack of DNA present in selected samples (e.g., dog hair cut instead of pulled out from the skin where the follicle DNA would have been much easier to isolate). Laboratory failures are actually not that common in school in the sense that there is no data or no correct answer; classroom science labs are designed to maximize success of the laboratory procedures for all student groups with correct expected outcomes. But this is not how

science typically works. In an interview at the end of the course, Mr. Lewis reflected on how the failure of the DNA barcoding labs to get DNA sequences became a productive event in his class:

a large number of our groups didn't get DNA sequences back at the end of the barcoding project and their first response often was I've failed, or we didn't do our lab right; something went wrong. And I think that's typical because the experiments that we do in high school are often experiments that have been repeated over and over and over and we know all the ins and outs and kinks and things that can go wrong and we can help the students get good results. But, this particular experiment was great because when they didn't get results, we could start a discussion about what real science actually was like.

The nature of this contemporary science investigation and chance for students to do real scientific work gave all students — no groups were successful at extracting DNA from every sample — experience with the real complications and consequences of scientific work. In the best conditions, making meaningful contributions to knowledge is complex and fraught with setbacks and failures. The upside, as Mr. Lewis notes in his interview, is that we could facilitate classroom conversation grounded in students experiences about actually happens in scientific work. This conversation came again when we took some of the students on a fieldtrip to a local science institute. Each group gave a short elevator speech summarizing their work to a boardroom of scientists and in almost every instance the scientists responded with statements about how difficult it is to extract DNA, especially on the first attempt, and that they often have to repeat and optimize laboratory procedures before they can make it work. Both of these instances spurred by the in classroom failure, lead to important epistemic and kinds of persons knowledge for students to develop about building scientific knowledge and persisting through

failure. They need to understand that these occurrences are normal and that scientists make progress by learning from and working through failures. This is connected to a broader learning principle common in project-based learning and engineering learning that students need to be able to encounter challenges and failures in order to learn.

As the project wrapped up, Erik, Jayna, Kelly, and David each choose to focus on a section of the proposal for continued funding template. Erik worked from information he gathered and summarized in the literature review and the group leaned on their lab experience to argue that the DNA extraction kit provided in the curriculum was not specific enough for their project and they expect they could be successful if they were able to use a kit that was designed specifically for working with highly processed foods such as cough drops. A further analysis of their written documents follows below. It is also a place in which school practices — especially the need to streamline procedures so all students can run a similar lab on the same day and materials can be purchased in bulk — constrain real science in the classroom. Yet, it is likely that students would have faced similar constraints in a laboratory setting where costs and material access can be prohibitive.

Reflecting on the entire unit, two students left comments about how much they enjoyed the project. One student said, “I feel like I’ve been extremely lucky to be in a class that does this project” and another wrote, “I like this WHOLE unit.”

**Group case study: Local biodiversity investigators.** Trevor, Allen, Austin, and Bailey were in the same class period as the cough drop group. Their group dynamics were different from the cough drop investigators and their project had a different outcome. Trevor, Allen, Austin, and Bailey sat close to the cough drop group and Austin and David collaborated on the tweet about strawberry DNA. Bailey and David had very similar questioning styles and concerns

in the class and would often take turns asking clarifying questions during classroom discussions, activities, and lectures. They were both curious and demanded time and detail to understand content and assignments or prompts. Neither David nor Bailey emerged as leaders in their project groups, but they did make significant contributions at times and were both concerned about understanding the steps of the project in detail. I examined their positions in their respective groups in Chapter 4.

Trevor, Allen, Austin, and Bailey consulted a list of ideas provided to them to help decide what DNA barcoding project they wanted to investigate that addressed something of local interest. Before solidifying their project idea, students went home and thought about various ideas and student spoke with a parent and noted, “I talked with my dad about ideas for research.” After discussion the following day, they settled on using DNA barcoding to investigate the biodiversity and invasive species present in a park close to their neighborhood. Reflecting back on this decision, the group members had varying opinions about how inventive their project work was. One member wrote, “Our project is creative compared to most of the class which chose to do food” while another member thought the project could have been more personally relevant, “...it could’ve been more creative and more relative to my group members interests.” Group work allows for more in depth investigation with effort from four people but it can also constrain the options for finding a project that is relevant to all group members interests. This represents a complexity often present in everyday workplaces in which people must collaborate on projects not directly connected to their interests. However, Trevor, Allen, Austin, and Bailey, benefited from working on a project related to place close to their everyday lives and activities.

With a focus on biodiversity and invasive species, the group made the decision to pursue the project because they valued the rationale, one student wrote, “We are doing something that

we are around everyday...no one seems to really think about what would happen if [invasive] species took over.” Planning together, the group formulated a research design plan with literature reviews about the history of the park under study, known invasive species present in the park, techniques for removal of invasive species, and general invasive species of the Pacific Northwest. After submitting the document on the online platform, a disciplinary expert with a Ph.D. in molecular and cellular biology and a strong commitment to biology education gave them feedback using track changes in word. She noted that the rationale was very good and relevant to both the community and the environment. She also asked for clarification on the research questioned wondering how they would determine if a species was invasive or native. Finally, she commented that it would be super cool if they were able to identify a new invasive species not yet found in the park.

To collect samples, all four students visited the local park to collect pieces of plants. They were the only group to report that they turned sample collection into a whole group activity outside of school time. During the week of wet laboratories to extract, amplify, and sequence DNA from samples, the group worked closely to understand each step and coordinate activity to successfully follow the complicated protocols. They made conscious effort to share access to the protocol steps, as one. As one student noted, “We all do work and we trade off doing things that only requires one person.”

A known issue with group work split into specific roles, is the subsequent lack of access to more advanced roles for students who did not get selected. This group did not seem to have a division of labor between the pipettor and the rest of the group. They actively shared responsibility and worked together to understand the complicated protocol. Another group member reflected that they, “followed all the directions and paper instructions given to [them].”

This statement sounds like students did a cookbook type laboratory experience but working through a step-by-step protocol to carry out a specific contemporary technique while working on a broader student-defined investigation is one instructional decision that allows for merging scientific practices with contemporary tools and techniques. Students designed the investigation around what the DNA barcoding technique could support. Ideally, students would get time to repeat and practice the techniques and continue to build on their DNA barcoding work. This would kick start their knowledge of techniques that could grow into building protocols of their own to alter and optimize the tools for their own purposes. As undergraduates in an interdisciplinary laboratory were able to contribute by building tools needed in the lab setting (Newstetter, Johri, & Wulf, 2008), the group noted that understanding of tools could continue to be an asset. One student reflected, “We are pretty confident with the tools, however, we could use a little more training.” For this group, familiarity with the tools and protocols proved to be an important knowledge-building asset.

On the fourth day of laboratories, the students were able to view the stained gel products from gel electrophoresis. They noticed one sample produced a dyed band and we proceeded to submit that sample to Genewiz for sequencing. Genewiz takes about 48 hours to sequence samples, is it possible to do DNA sequencing in the classroom but not at the level required for DNA barcoding. Sending the sample away denies an opportunity to engage more deeply, however, it is currently common practice in the sciences to use outside parties to do the sequencing of large numbers of samples. This need to send away could undercut the vision of the Framework, but it also allows for more sophisticated work to be done in the classroom without needing all the materials and expertise needed to engage in the full process of sequencing.

The next Monday, we had uploaded a document with all the sequences to the platform, and the students downloaded the document, copy and pasted their one DNA sequence into the BLAST nucleotide database. In the analysis section of their proposal for funding, the students noted, “The DNA sequenced matched with a plant called *Oemleria cerasiformis*, which is a northwestern Indian Plum. It is a Northwest deciduous shrub,” which indicated to the reader that the sample was not an invasive species. The group then used this outcome and data to motivate their persuasive argument for continued funding. In their proposal for funding, they argued that they just got a “small taste” of what DNA barcoding could reveal about the park and that with further funding they could “make a true discovery.” Even though this group was able to analyze DNA from one sequence, their other four samples were not successfully sequenced. This twenty percent return rate on samples was representative of all the samples across all five classes and no groups were able to get a DNA sequence from every sample.

Across the two case studies it is important to highlight the features of learning environment that allow for students to engage in scientific practices in the context of real scientific work. Shirley Brice Heath (2012a) argues that out-of-school and beyond family interactions have these affordances that give young people opportunities “to have hours of practice within adult roles in different places with different audiences” (p. 104). The interactions include face-to-face interactions with experts around “creative projects that required their sustained commitments, dedicated imitation and practice, and a curiosity that pushed them to know and do more” (Heath, 2012a, p. 103). These case studies begin to demonstrate that these important developmental interactions and contexts can happen in school settings. The DNA barcoding project in a school setting included additional features that support creative, sustained practice in the work. The first is the opportunity for failure and continued pursuit of the work,

which is a key complexity in scientific and engineering work. Supported use of technology and contemporary scientific tools gave students the resources to pursue scientific work they wanted to know more about. Lastly, the use of a common contemporary scientific technique to ground student investigations allowed students to gain practice and expertise with a set of scientific materials. With these features in play in the learning environment students could engage with the knowledge of science as made up embodied practices (Lynch, 1997). The case studies led to a systematic analysis of student documents across all twelve groups to understand conceptual features of students' practice-focused work that further investigates how these features play out in the context of the four bundles of practices theoretical framework.

## **Student Artifact Analysis**

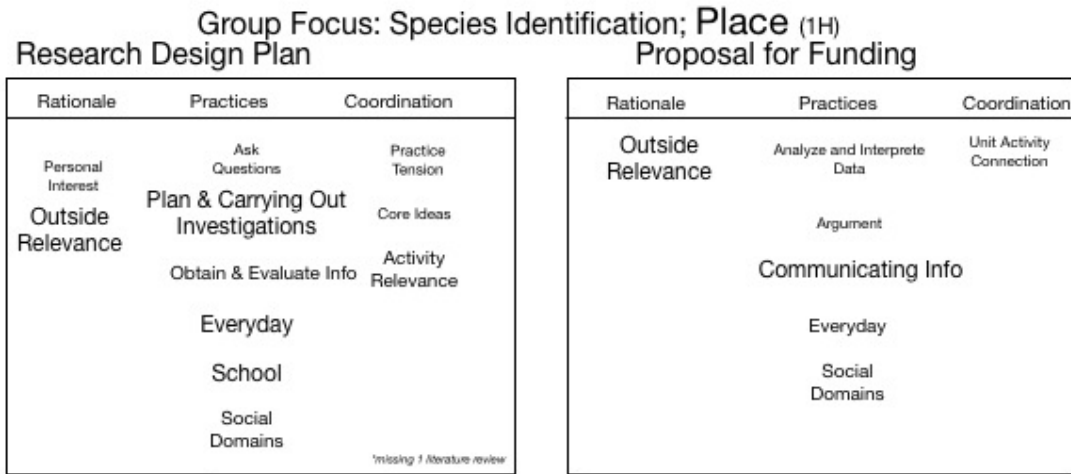
### **Analysis of Student Documents**

Students' participation in practices occurred as part project group work across the unit and was seen in in discussion, written work, and "wet" laboratories (where students are doing biochemical bench work). To understand how this mutual engagement in action (Wegner, 1998) can be inferred from written work, I analyzed student project work at two time points in the unit – when students planned their DNA barcoding research (Research Design Plan, time 1) and when students wrote about their findings in a scientific proposal for funding (Proposal for Funding, time 2). These were the most substantial reading and writing assignments embedded in the unit. Using a grounded theory approach, I coded the documents from these two time points for all student groups. After initially analyzing and coding 16% of the data, I revisited my theoretical framework and refined codes to closely account for seeing epistemic science practices in students' written work and student reflections. The most notable code revision occurred when the data clearly indicated an additional practice bundle students attended to in their contemporary

scientific investigations. This addition to the design framework, as Relevant Social Domains, indicates bundles of practices carried out by institutions or organizations (e.g., the FDA) that students note as relevant to the scientific work they were conducting. After coding of the entire data set, I trained an additional coder on the coding scheme on 16% of the data, followed by an interrater reliability test on 16% of the data with results of 85% agreement across coders. This analysis resulted in a set of conceptual themes identified in the student writing that could be analyzed across the two time points.

**Conceptual themes across time.** I examined the epistemic alignment in the bundles of social practices at play through a two level document analysis. First, I looked at the frequency of the code and the co-occurrence of codes across all 21 student produced documents to determine themes. Second, codes were grouped into four categories: (a) *Group focus*, descriptor codes to categorize the type of investigation students pursued; (b) *Rationale*, codes to describe students' reasoning and motivation for choosing and pursuing the investigation focus; (c) *Practices*, specific scientific practices along with bundles of practices (everyday, scientific, school, or social domains) that students' invoke in their work; and (d) *Coordination*, the links and separations — places in which coordination did not occur — between practices, core ideas, and activities present in student work. Codes were grouped and arranged into summative visual representations for each document that demonstrate the frequency of codes as well as the change in document focus from time one (research design plan) to time two (proposal for funding). In the representation, size of text corresponds to frequency of code appearance. For example, Figure 8, shows the conceptual themes across time for one group that investigated the presence of pink slime in meat, a topic well represented in the news at the time of the enactment. In the group's

research design plan, outside relevance was coded at least three times, obtaining, evaluating, and communicating information was coded twice, and personal interest was coded once.



*Figure 8.* Conceptual themes in pink slime investigation.

As detailed in the next section, these representations allow for a comparative analysis of how groups rationalized their studies, how they engaged in practices, and how they coordinated their work with salient dimensions of the investigation.

### **Shared and Distinct Conceptual Features of Student Work**

The conceptual theme representations for all groups across the two points are presented on adjacent pages (Figure 9). The following sections present a comparative analysis of the various thematic dimensions of the documents as revealed by the representations.

## Group Focus: Species Identification; **Place** (Pink Slime)

### Research Design Plan

Rationale	Practices	Coordination
Personal Interest	Ask Questions	Practice Separation
Outside Relevance	<b>Plan &amp; Carrying Out Investigations</b>	Core Ideas
	Obtain & Evaluate Info	Activity Relevance
	Everyday	
	School	
	Social Domains	
		<small>*missing 1 literature review</small>

### Proposal for Funding

Rationale	Practices	Coordination
<b>Outside Relevance</b>	Analyze and Interpret Data	Unit Activity Connection
	Argument	
	<b>Communicating Info</b>	
	Everyday	
	Social Domains	

## Group Focus: Species Identification; **Fraud** (Herbal Medicine Blends)

### Research Design Plan

Rationale	Practices	Coordination
Personal Interest	Ask Questions	<b>Practice Separation</b>
Personal Identity	<b>Plan &amp; Carry Out Investigations</b>	Core Ideas
Outside Relevance	Obtain & Evaluate Info	Activity Relevance
	Everyday	
	School	
	Social Domains	

### Proposal for Funding

Rationale	Practices	Coordination
Personal Interest	Analyze & Interpret Data	Core Ideas
<b>Outside Relevance</b>	Argument	
	<b>Communicate Info</b>	
	Everyday	
	Social Domains	

## Group Focus: Species Identification; **Biodiversity Place** (Invasive Species in Park)

### Research Design Plan

Rationale	Practices	Coordination
Personal Interest	Ask Questions	Core Ideas
Outside Relevance	<b>Plan &amp; Carry Out Investigations</b>	Activity Relevance
	Obtain & Evaluate Info	
	School	

### Proposal for Funding

Rationale	Practices	Coordination
<b>Outside Relevance</b>	<b>Communicate Info</b>	Core Ideas
	Argument	
		<small>*missing rationale for continued funding</small>



**Group Focus: Species Identification; Biodiversity; Place (Invasive Species)**

**Research Design Plan**

Rationale	Practices	Coordination
Personal Relevance	Ask Questions	Practice Link
Community Relevance	<b>Plan &amp; Carry Out Investigations</b>	<b>Activity Relevance</b>
	<b>Obtain &amp; Evaluate Info</b>	
	Everyday	
	Social Domains	

**Proposal for Funding**

Rationale	Practices	Coordination
Personal Relevance	Analyze & Interpret Data	Activity Relevance
Community Relevance	Argument	
	<b>Communicate Info</b>	

**Group Focus: Species Identification; Fraud; Place (Pet Store Birds)**

**Research Design Plan**

Rationale	Practices	Coordination
Personal Relevance	Ask Questions	Activity Relevance
Outside Relevance	<b>Plan &amp; Carry Out Investigations</b>	
	Obtain & Evaluate Info	
	Everyday	
	Social Domains	
	School	<i>*missing two literature reviews</i>

**Proposal for Funding**

Rationale	Practices	Coordination
Outside Relevance	Analyze & Interpret Data	Practice Separation
	Argument	
	<b>Communicate Info</b>	
	School	

**Group Focus: Species Identification; Fraud (Tuna)**

**Research Design Plan**

Rationale	Practices	Coordination
Outside Relevance	Ask Questions	Activity Relevance
	<b>Plan &amp; Carry Out Investigations</b>	
	Obtain & Evaluate Info	
	Social Domains	
		<i>*missing two literature reviews</i>

**Proposal for Funding**

Rationale	Practices	Coordination
Outside Relevance	Argument	
Personal Interest	<b>Communicate Info</b>	
	Everyday	
		<i>*missing overview of DNA Barcoding</i>

**Group Focus: Species Identification (Herbal Supplements)**

**Research Design Plan**

Rationale	Practices	Coordination
Personal Interest	Ask Questions	Core Ideas
	Plan & Carry Out Investigations	Activity Relevance
	Obtain & Evaluate Info	
	Everyday	
	School	
		<i>*missing two literature reviews</i>

**Proposal for Funding**

Rationale	Practices	Coordination
		<i>*missing entire proposal</i>

**Group Focus: Species Identification; Comparative; Place (Mushrooms)**

**Research Design Plan**

Rationale	Practices	Coordination
	Ask Questions	
	Plan & Carry Out Investigations	
	Everyday	
	Social Domains	
	School	
		<i>*missing one literature review</i>

**Proposal for Funding**

Rationale	Practices	Coordination
		<i>*missing entire proposal</i>

**Group Focus: Species Identification; Fraud (Cat Food)**

**Research Design Plan**

Rationale	Practices	Coordination
Personal Relevance	Ask Questions	Activity Relevance
Outside Relevance	Plan & Carry Out Investigations	
	Obtain & Evaluate Info	
	Social Domains	
	Everyday	
	School	

**Proposal for Funding**

Rationale	Practices	Coordination
Outside Relevance	Analyze & Interpret Data	
	Argument	
	Communicate Info	
		<i>*missing methods &amp; findings</i>

Figure 9. Conceptual theme representations for each group.

**Group focus.** All groups engaged in a species identification project using a shared scientific technique and the tools available. One student left his group and attempted to

repurpose the tools to examine whether or not tomatoes from a store were genetically modified but he was not able to complete the investigation. In addition to species identification, groups put different emphases on their work, focusing on one or more of the types of issues that DNA barcoding could address. These different purposes included: fraud (six groups); examination of biodiversity in a specific location (two groups); the comparison of two samples (two groups), and place-focused investigations in the community (six groups). These last six groups focused on investigating an issue using DNA barcoding in a specific place and these investigations spanned all types of investigations. In these place-focused investigations, students' work was relevant to a place in their community and the project was clearly linked to that place from start to finish.

As was intended in the design, the shared DNA barcoding technique allowed students to pursue a variety of investigations that were of interest to them. This is in contrast with many confirmatory science experiments in school in which students are all pursuing the same investigational purpose. This flexibility came with the complexity that students sometimes wanted to investigate issues that required methodological techniques other than DNA barcoding. Utilization of a contemporary scientific technique that can be used for different purposes is a design strategy for increasing complexity and choice for students.

**Relevance and rationale.** The curriculum was designed to provide students with the opportunity of motivating their DNA barcoding investigation based on personal, community or societal interest. Students' general rationale for their project choices from their Research Design Plan to their Proposal for Continued Funding usually stayed consistent across the investigation. So if a group employed outside relevance (e.g., the issue understudy was relevant to people beyond the group and immediate community; for example, a general issue like food consumption) in their Research Design Plan, they also cited outside relevance in their Proposals.

However, groups often cited personal interest or relevance along with outside relevance in the Research Design Plan but in the Proposal they cited only outside relevance, an appeal to a greater population of people. In one instance, a group noted their interest in the project was somewhat fueled by a group member's middle name that was also the name of a plant; this was coded as personal identity and it was the only time identity statements had a role in project rationale.

Writing coherent and clear rationale for research studies is an important skill and we also know that students are more likely to be engaged in learning when activities are connected to their lives or their local contexts. Overall, across groups, the slight change from a personal focus to an outside relevance focus highlights students' attention to audience in their scientific writing. This could have been prompted by the purpose of each document. It is encouraging to see students attending to audience and purpose in this way and it is reflective of how writing in science gets done. Lemke (1990) writes "...formal scientific style is not the whole of science. *Teachers should use all of the stylistic and rhetorical means available to communicate science to students*" (p. 174, italics in the original). I argue students should also have practice communicating science — in this case, communicating scientific relevance — in a multitude of ways.

### **Student Engagement in Practices**

Analyzing the conceptual theme representations allows for understanding the prevalence of the practices in the student artifacts. In this section, I interpret the patterns of indicators present for student engagement in scientific practices, school practices, everyday practices, and their referencing of relevant social domains.

**Scientific practices.** The curriculum was designed to engage students in specific epistemic practices of science in ways that were motivated by the investigation they were conducting and the scientific technique they were employing.

The scientific practices that students clearly engaged in as they completed the two documents were Planning and Carrying Out, Investigation and Obtaining, Evaluating, and Communicating Information, and Constructing Arguments from Evidence. Not surprisingly, this strongly fits with the instructional design focus of the unit. Unlike traditional school science investigations, however, these practices co-occurred and students employed the outcomes of a practice to inform their engagement in the other practices. For example, students decided what type of investigation they would pursue, agreed on a focus to that investigation, obtained and evaluated information related to their investigation, reflected on how that information informed or brought up questions or concerns about their investigation, and continued to search for and cite information in their proposals for continued funding. The information drawn from this practice was often used as evidence or warrant in the proposal writing. The prevalence of these practices across time in the unit brings up an opportunity to carefully analyze the mutual dependency of practices especially at the transition points when they build on and inform each other. I will use Toulmin's (1958) argumentation framework to detail the epistemic alignment (or lack thereof) between scientific practices across time and across student artifacts.

Students also formulated a scientific question during the Research Design phase of work. However, this was not an instructional focus of the unit and many student questions reflected a combination of a scientifically written question with an evaluative component about the implications of the work. For example, one group asked: "Do certain companies not list labels on their medical herbs, or a substance that is dangerous?"

Student groups seem to vary in their engagement in the information practice in the research design plan. Students were given autonomy in choosing which topics to pursue for their literature review sections. Students worked individually on different topics and then combined the writing in the final iteration of their group's research design plan. Overall, students obtained and evaluated information from online sources effectively. The autonomy in topic gave students a wide range of information to work from and therefore groups ended up with information that varied in its applicability to impact research design. In some cases, students noted that the literature review provided more background information (e.g. history of the local park and surrounding lands) instead of information that directly impact the study design (e.g., typical invasive species to look for).

The document analysis reveals that students did successfully engage in the target scientific practices, with some variation present across groups. The supports and resources for the project investigations designed into the curriculum supported student engagement in the relevant science practices. The fact that this was evident in the written documents of student groups also indicated that the extended writing assignments built into the project largely succeeded in becoming part of students' investigations.

**School Practices.** The curriculum was designed to for innovative practice-focused instruction in the classroom. School practices (e.g., test assessment, cost of sample collection, time constraints) influenced how teachers enacted the unit, which in turn shaped students' opportunities to learn in practices.. The school practice code occurred across both documents for the majority of groups (10 of 12). This code acted as a catch-all code to identify when school practices were invoked by students. Three major school practices were coded in the data. The first, "school work" showed up in the literature review portion of the Research Design Plan and

was used to indicate that a student treated the homework as a detached assignment without attending to the implications the literature review information had for their investigation. This was evident in the copy and pasting directly from websites or the use of a list format to summarize a website. The second, “expected contributions” indicated the times (specifically in the sample collection planning) when students described how each group member would contribute to a part of the investigation, the expenses associated with the investigation or the expected procrastination as barriers for being ready to complete the investigation. However, these could also be coded as real barriers that occur in in most workplaces. Finally, school practices also were coded in the Proposals when students referred to a school practice as hindering their investigation, such as, only having one attempt at the DNA barcoding while still learning appropriate techniques.

School practices that were visible in students’ written work were largely negative ones that interfere with the project investigation. The context of school does have affordances that out-of-school contexts do not. For example, attendance at school is compulsory so student attendance and turnover is much less of an issue than in other learning settings. In addition, implicitly the school practice of engaging in lessons and doing assignments allowed for the project investigation to be carried out over multiple weeks—in ways that are difficult to do in afterschool spaces.. Those school practices benefit the investigation work. Finally, the school was set up with some laboratory space and equipment that made it possible to work with professional-level protocols.

In student work school practices appear to be negative but when considering the larger context of the work, the school space and organizational routines also have positive affordances for students to do contemporary scientific work in the classroom. The school practices evident in

the student work could all be attributed the fact that this was the first time the students had done a project in their classroom and the instructional model was different than they had experienced throughout the year. It was evident from Chapter 2 that coordination of a classroom culture supportive of investigative project takes time and resources to develop. The implication is that student work will benefit from a supportive classroom culture.

**Everyday practices.** Student learning is supported when students have the opportunity to make connections between their work in the classroom and their individual and community lives outside of the classroom (e.g., Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). A major design strategy of the curriculum was for students to leverage the DNA barcoding technique to address a problem related to their own interests or everyday practices.

Reference to Everyday practices (i.e., the use of herbal medicines for preventative health care or the meat eating habits of a group of people) were present in the work of 11 of the 12 groups across both time points. This is to be expected given students were asked to decide on the topic of study that was interested and relevant to them and to provide a rationale for that study. Often students leveraged everyday knowledge and experiences to explain the importance of their study. Once students gathered more information, these everyday practices were expanded via online research, which prompted the need for a set of practices I refer to as relevant social domains.

Eleven groups explicitly noted a connection to everyday practices in their written documents. Table 1 shows each group's overall topic of study and the connection to everyday practices.

Table 1. Everyday Practices Connections in Students' Investigations

<b>Group Topic</b>	<b>Investigative Question</b>	<b>Everyday Interest Connection</b>
Pink Slime	What is in the meat we eat that we don't know about?	We believe the public needs to know what they are eating before they eat it. This topic is important because America continues to grow more and more unhealthy because of this new pink slime controversy.
Herbal Medicine Blends	What herbs are in the common herbal medicines that are sold in many apothecaries, and do they match with what they say they are.	Kinds of Herbal Medicine: Aloe Vera: common herb; found in shampoo, hand lotion, etc.
Pepperoni Sticks	What ingredients are inside pepperoni sticks? Are there any ingredients not on the label? What are the un-known ingredients of pepperoni sticks? Are there different ingredients in different pepperoni sticks? The main question is there ingredients that are not on the label?	Because we all have eaten a pepperoni stick before and when [student] brought up what she saw when she looked at the ingredients – we decided we would like to find out more about what is inside the pepperoni and if there are different ingredients in different brands and pepperoni sticks from different places.
Cough Drops	Are there ingredients in natural cough drops that are not listed on the package?	This is important to know because some people may have allergies to specific plants that may not be listed.
Medicinal Herbs	Do certain companies not list labels on their medical herbs, or a substance that is dangerous?	Patients with AIDS usually take garlic to help aid their number of T-Cells in their body. Garlic is grown all around the world. (Everyday uses of herbal medicines)
Invasive Species	What types of invasive species are found in [Local] Park?	We selected this problem because it is close to all of us and has an effect on the citizens that use [Local] Park. Also this problem has an effect on the overall ecosystem of our area.
Pet Store Birds	What types of birds are generally sold at pet stores? Are they legal? Can we find documented cases of times when the pet stores aren't selling the birds that they said they are?	It is interesting to us because we like birds.
Tuna	Is there any other fish mixed in with the tuna in canned tuna, a tuna steak, or sushi? Also are there different species of tuna?	This topic is important because we want to make sure people are really eating what is on the label and not some cheap or potentially dangerous fraud.
Herbal Supplements	What herbs and plants are really in the remedies that we take?	Our group selected this topic because we are interested in natural ways to cure common ailments. We are also interested in seeing what is really in supplements that help us get better.
Mushrooms	How does the DNA of wild mushrooms compare to the DNA of store bought mushrooms?	Its important to know what's in the food you're eating of course, and it will be interesting to see how the content of wild mushrooms compare to the ones in the store. It also might help tell us where our mushrooms are coming from, or what is in them.
Cat Food	What vegetables and meat are found in wet cat food, and do they match up with what the ingredients label/company claims that the products include?	We find this topic to be important because we want to assure that what we feed our cats is safe and natural. We want to make sure that our animals are safe and what the contents in the food are safe.

Everyday practices references showed up in a variety of ways. First, students noted everyday activities of interest such as eating, taking supplements, or feeding cats. Other groups mentioned a common occurrence or ailment they are likely to have experience with such as cancer and allergies. Finally, groups everyday practice connections were linked with local places. In most cases students' investigations were linked with everyday practices in the rationale section of their research design plans. It is important to note that students were not asked to spend time revising their investigative questions and the teacher and researcher did not assess students on their ability to write a testable scientific question. Readers will notice that some of the students' questions contain evaluative elements.

With access to a contemporary scientific tool that can address many different problems, students are able to connect their investigation design elements to everyday practices. Given the variety of project topics, it is not surprising that students vary in the way they make connections. It is also likely that the everyday language and evaluative elements present in students' investigative questions are there because students are looping the rationale of their study into the question. The question becomes a combination of research question and future translation or implications. Scientific practices embedded in the use of contemporary techniques support students to make design investigations related to their everyday experiences.

**Relevant social domains.** This category of practices represents a new insight and addition to the theoretical design framework through analysis of student documents. Relevant social domains are the bundles of practices employed by institutions or organizations (e.g., the FDA) that students refer to during their own scientific work. This practice bundle category was used to capture instances in which students described organizational, institutional, corporate, or political practices that influenced or informed their investigation.

The practices of relevant social domains were referred to by 10 of 12 groups in either their Research Design Plan, Proposal, or both. In the Research Design Plan work phase, this occurred at the Investigation – Info Practice transition point when students were asked to relate the information gathered via literature review to their investigation and they used this information to bolster the importance of their impending work. One group found an article related to the Food and Drug Administration’s regulative abilities and wrote this means their work could have implications because, “The contents of this article summarize how it is getting tougher for the FDA to perform food safety tests on imported food.” Another group studying tuna referenced a request for a trade ban on blue fin tuna at the Convention on International Trade in Endangered Species. A third group also obtained information about a trade practice that influenced their investigation. Writing about the illegal parrot trade, they wrote:

The illegal parrot trade is a multi-million dollar business. The United States before 1992 made up 80% of the parrot trade, but in 1992 the United States passed the Wild Bird Conservation Act. This act banned the importation of parrots into the United States. About two million parrots sold on the world market during 1990-1994.

The use of the information practice in the midst of planning an investigation allowed students to leverage information to support the rationale of their projects.

In the Proposal phase, students referred to these relevant domains of practices to give a rationale for continued funding. This linkage of the investigation topic to practices of relevant social domains, made the work real for students with legitimate goals and implications that they came back to even when the initial experiments failed. Students’ writing indicated they believed the outcomes of their project would have legitimate and actionable implications, which gives

them the opportunity to make meaningful contributions to the field. Yet the timing of school practice limitations and lack of time to repeat laboratory procedures hinder this from becoming actualized in standard formal learning environments. Generally referring to companies that make meat products, the group studying pink slime wrote, “This project is important because we can understand what is in our food and expose companies that are lying about what is in our meat.” Their goal was to gain actionable data to “expose” the practices in this relevant social domain. The cough drop investigators made a similar fraud-related statement about the practices of companies that produce cough drops. They wrote: “... it is possible that a company would inhibit the advertisement of a certain ingredient with potential to cause dangerous side effects, or an allergic reaction, so that the public would more readily buy their product.” In the design phase of the work, students obtained and made use of information related to the practices of industries and then in the proposal phase of the work, students noted how they could use their research to expose or inform the public about data that might contradict the public’s perception of certain companies’ practices.

Often in PBL learning environments, students are asked to do “realistic” versions of scientific problems often acting in stakeholder roles that simulate the decision making processes of professionals in related fields. The question is: Can students engage in real project work in the context of school? This finding represents a large step towards enlisting learners and their interests in real science in which they have access to real models and real experts. It is possible in formal learning environments to design learning experiences that allow students to coordinate the many practices they engage in or run into across settings to participate in real scientific work. This coordination occurred between bundles of practices and is evident in student work. Participation in real scientific work is important for enlisting learners into future scientific work

and building need for learners' talents and interests in the scientific endeavor, as Shirley Brice Heath (2012b) argues:

Group identity figures centrally not only for experts in science, but also for novices who often find science through “real” projects that need their particular talents and interests. Through “relevance” is often touted as critical for enticing the young into science, research has shown that “real” projects enlist learners far more easily than projects that are only “realistic.” Herein lies the problem of “relevance” and its relationship to “real” as distinct from “realistic.” Just as diverse levels and kinds of knowledge and skills create groups of expert scientists, so group projects that deeply engage novices must include a range of expertise and interests and ideally access to “real” experts or models (p. 257)

This fourth bundle of practices —relevant social domains — added to the theoretical design framework allows for students to employ scientific practices to gather information and design scientific investigations that have implications for real social domains and the practices of these relevant social domains influence the goal or issue at stake in students' performance of practices.

### **Coordination**

Coordination codes look at the how the four bundles of practices interact with each other in student's investigations and how these interactions have an effect on how the investigation plays out for students.

**Links and separations between practices.** Links represent “easy flow” from one practice into another versus separations, which represent “disruptions” as students moved from one practice into another. Links were instances in which students referenced congruencies

between two or more bundles of practices in the context of their investigation, while separation between practices occurred when students noted or referred to cases of action in which their investigations were impacted by issues that arose (were expected to arise, or were deemed a definite impact by the students) because of the negative interaction between practice bundles.

Practice links occurred rarely as a code because it served to note the links between bundles of practices (not practices within bundles). When practice links were noted, it occurred because students wrote that an analytical technique of science (generally, DNA barcoding) was well suited to address or solve issues related to an everyday or social domain practice. This was coded when students explicitly discuss the affordances of DNA barcoding in relation to their topic of investigation. Another code conceptual code tied to links between practice, the *Activity Relevance* code, was employed to note when students made deliberate statements that deemed one practice (usually the scientific Information practice) relevant to the work of another practice (usually the Investigation practice). Due to the instructional design and sequencing of students' production of the two documents under study, this code occurred only in student's literature reviews as part of the Research Design Plan, which was the most substantial piece of individual writing students were asked to contribute to the group plan. This clear coordination between scientific practices highlighted an interesting intersection and underdeveloped area of study – the detailed analysis of a specific transition in the cascade of practices – which motivated further analysis at this point of epistemic alignment.

Tensions and explicit separations between practices occur when the practices of one bundle (e.g., school practices) hinder participation in another bundle (e.g., scientific practices), with the hindrance focus on disrupting scientific practices. The analysis focused specifically on the scientific practices related to DNA barcoding. The most prevalent tension between practices

showed up when school practices hindered students DNA barcoding work. As discussed in the school practices analysis, instructional practices of school such as homework assignment structure and purpose and class periods lasting less than one hour, created conditions that were not optimal for the complex investigative work. For example, in three of the Research Design Plans, at least one group member treated the literature review as a strict homework assignment without making connections between the resources, their own summaries, and the investigation. Missing this step, the work did not show evidence of deep student engagement in the information practice at that time point in the unit. These instances are important in that not every group member made a “beyond school practice attempt” at epistemic alignment between practices. It seems likely that this is attributable to the engrained and repetitive school practice of homework that is not revisited or useful for ongoing work in the classroom.

In the Proposal phase of work, the tension between school and scientific practices were all tied to the constraints of the school setting or instructional design that did not allow students time or opportunity to get specialized materials for DNA extraction (including kits and primers [used in context of the bench work]) or did not allow for repetition of the extraction process.

In scientific work, failure is common but in classrooms, laboratories are set up to be confirmatory and have correct answers or values. The project tried to allow for real scientific work in a confirmatory lab setting with similar expectations. This meant that groups did not have time, resources, or the background to identify and seek out resources that scientists may have been able to acquire. Students were also running laboratories in back to back periods with the same set of reagents and there were certainly many chances of contamination. In addition, while students gained on the ground expertise as worked through the labs, they likely did not start with expertise to know exactly what each step was doing and how to ensure success at each level of a

complex protocol. These show up in students' discussion of the Methods/Findings and Rationale for Continued Funding section of the proposal when they explain why they did not get data and what next steps might ensure that happened in an additional round of work.

**Disciplinary core ideas of science.** A known issue with foregrounding contemporary scientific issues and techniques in project-based, practice-focused instruction is the disconnect between the grade band core ideas students are responsible for understanding and the complex ideas that build upon those to inform the contemporary work in the sciences. When students made connections between NGSS core ideas about genetics (e.g., structure and function or inheritance) in relation to their DNA barcoding work, the core idea code was used. Students did not have to be accurate in their understandings evident in their statements.

When students describe how they will use DNA barcoding, specifically in the literature review of the Research Design Plan or the overview of DNA barcoding for the Proposal, 42% of the groups utilized specifics of the core idea—the inheritance of traits—mainly that species have unique DNA that allows scientists to distinguish between species and that all the cells in a sample or organism will have the same DNA with the implication that DNA barcoding cannot distinguish between types of tissues within a sample from one organism. This occurred in these groups specifically because the topics of their projects (e.g. investigating the pink slime issue in meat production) required students to develop a detailed understanding of what DNA barcoding could or could not detect. Other groups studying, for example, the species of plants in a given area, did not necessarily need to refer to this distinction in their written work. Instructionally, this project was embedded in a unit that time and assessment devoted to content, which can be seen in the analysis of the pre- and post-test data. With respect to the inheritance of traits, students improved from pre- to post-test on all items related to that core idea.

It continues to be important for designers and researchers to identify features of instructional models that allow for deep integration of core ideas during students' investigation of contemporary scientific issues. One way to do this could be to layer in prompts that asks students to make clear connections between the contemporary scientific techniques at the heart of the project and the core ideas of the grade band. This will also help inform instructional strategies that further address the goals of the NGSS and students' opportunities for learning through performances that intertwine scientific and engineering practices, core ideas, and crosscutting concepts.

**Connections across time and space.** Over the course of an eight-week curriculum with ambitious project components, it can become difficult to see connections between the disparate activities and requests of students. In focus groups related to other curriculum units, students voiced the concern that sometimes it was difficult to follow all the ongoing activities within the curriculum. The connections code served as a way to identify when students made connections between their project work and in or out-of-school activities. Connections occurred when students made clear statements of connection between their project and out of school activity (one instance), their project and other unit activities (two instances). While this code occurrence is small, it is important to note that in a few cases students incorporated introductory activities about DNA barcoding into their own work. For example, one group noted that the extraction process was similar to the extraction of DNA from strawberries that was done at the beginning of the unit. The out of school connection was made when a group described the out of school situation that lead to the desire to study what species of meat were used in pepperoni sticks. Ideally, this presence of this code would increase as clear ties between unit activities are redesign and made explicit to students.

The conceptual themes analysis of two time points of student group work illuminate the multitude of practices — scientific, everyday, school, and social domains — present when students are supported to design contemporary DNA barcoding investigations. The common scientific technique, DNA barcoding, afforded the option for students to pursue investigations on a spectrum of species identification issues relevant to both their local communities and the larger society. Students weaved the rationale and importance of their project choices throughout their written documents and these documents revealed that students were able to make clear connections between the investigation practice and the information practice. A major theme that carried throughout was students' attention to the practices of relevant social domains when designing their investigations in the research design plan and describing the potential implications of their future work in the proposal for continued funding.

The interactions of the practices of relevant social domains and the scientific practices in the DNA barcoding work created real circumstances and complexities for students to navigate and leverage in the work. Attention to all four bundles of practices in curriculum design and instructional supports allows the practices of each bundle to support the scientific practices. Of specific interest in this model was the interaction between the investigation practice, the information practice and the argumentation practice when students' had a goal of securing continued funding for their work.

### **Argument Analysis of Student Connections between Practices**

Students' deliberate connections between the Investigation, Info, and Argumentation practices identified through the conceptual themes analysis motivated a detailed analysis of the alignment and misalignment between these epistemic practices (Rouse, 1996) as a way to understand the

quality of the alignment work students were doing as they connected across the entire investigation when asked to make arguments for continued funding.

Toulmin's micro-structure for argumentation has been used widely in science education as a way to scaffold and interpret student's evidence-based arguments (e.g., Bell & Linn, 2000). Toulmin's argumentation structure can be used to highlight the degree to which, and in what ways, claims are supported and rebutted. The analysis of the argument through a Toulmin (1958) framework, is embedded in the social practices of the students as demonstrated in their written work. In other analyses (Chapter 4), I have examined the practice-linked identity moments of the learners as they interact in key moments in the investigation. Students are able to construct arguments for why they should be funded by drawing on evidence, supporting those with warrants and backing, developed in work conducted across three weeks to plan and carry out investigations, obtain and communicate information, argue with peers, and analysis of data.

The act of constructing arguments in the context of continuing the work, an authentic task of researchers not traditionally seen in school, afforded students opportunity to align scientific practices the engaged in across the unit. For example, the group investigating pink slime (see Figure 10) made the claim: "Many Americans want to buy high quality food but large corporations want to spend less to mass-produce goods and we want to educate the people about this because their health is at risk." This group did not successfully extract DNA from their samples which is evident in their warrant—"We fear the reason we had no DNA is because research we did said that meat is sprayed and contaminated with harsh chemicals and composed of synthetic fillers"—and their qualifier—"This will be a long process because we have to eradicate human error from the equation before we can have an accurate solution." The warrant draws on both their Information practice (i.e., "the research we did") and the Investigation

practice (i.e., “we had no DNA”) as they leveraged both practices to bolster their claim. Similarly, the qualifier, represents a reflection on the extraction process and the human component of laboratory work. They recognize the need to gain further expertise in the laboratory techniques to successfully carry out the future work. As is common in most argumentation, especially in the context of a proposal for funding, this group and the others did not include a rebuttal to their own claim.

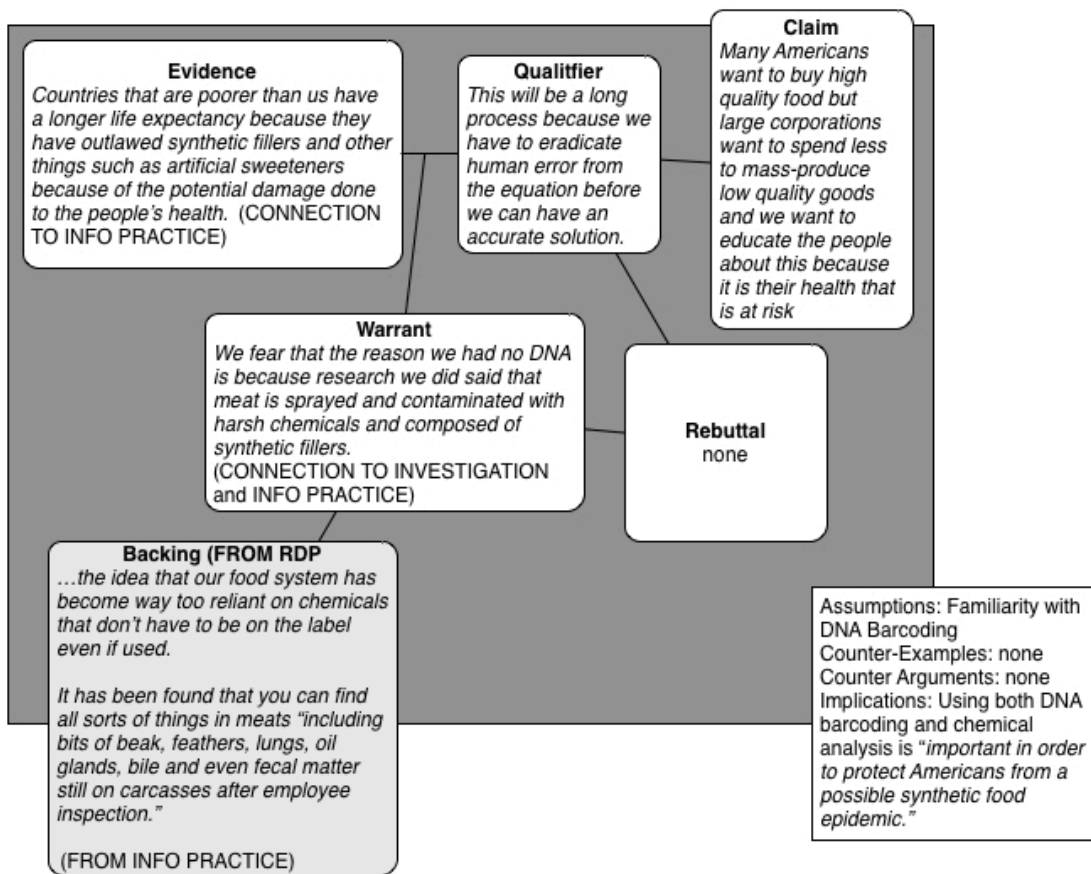


Figure 10. Toulmin analysis of pink slime argument for continued funding.

The structure of groups' arguments varies depending on the outcome of their investigation as well as the direction in which they decided to take the future work. The pink slime group did not get DNA results back from the laboratory and therefore relied on data from the literature review as evidence for their claim—"countries that are poorer than us have a longer

life span because they have outlawed synthetic fillers and other things such as synthetic sweeteners....” Given the initial failure of their investigation, the group needed to pull evidence from a different source and they still believed their investigation was important but that it needed to be bolstered with additional analysis to understand the problem with pink slime and synthetic fillers. The group offered a solution to use both DNA barcoding and chemical analysis of meat because “[it] is important in order to protect Americans from a possible synthetic food epidemic.” This statement served as the implication for their argument and also served to demonstrate the expansiveness of their thinking around uses of DNA barcoding and the need for additional analytical techniques.

In contrast, the group studying the biodiversity of a local park (see Figure 11) did successfully extract and sequence one of five of their samples. Their claim is focused on the discovery of new or invasive species in the local park, they stated: “We want to argue that with enough time and funding for a larger sample size that we could make a true discovery...” The statement was warranted with the second clause: “that [such an investigation] could be beneficial to Discovery Park’s delicate ecosystem.” Contrary to the Pink Slime group, this group could draw on empirical data from their investigation to provide evidence for their claim: “After seeing the preliminary results of our samples, we believe that it is important to continue getting samples because only one out [of] five of the samples we sent in returned with a species identification leaving us with only a small taste of what we could actually find.” The group employs their investigation data with an emotional twist to connect it back to the claim about making a discovery. This is to be expected given the ongoing nature of the work and the complexity that occurs when multiple practices are intertwined in an investigation. As documented in the initial analysis, the students were engaged in a non-linear, more realistic cascade of practices that

culminated not in a concluding statement as would be expected in science classrooms but a argument for scientific investigation work. However, when students are involved in real science, it is not reasonable to expect them to have arguments supported by evidence they have collected themselves.

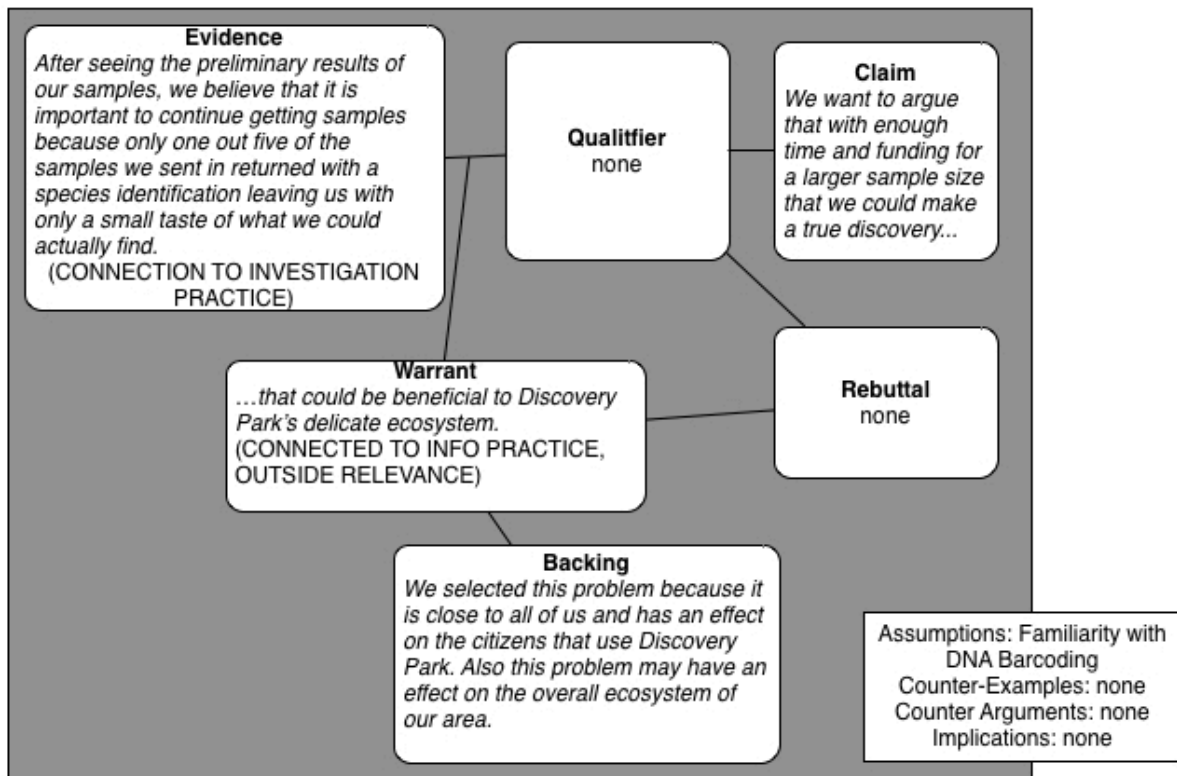


Figure 11. Toulmin analysis of biodiversity in local park argument for continued funding.

Comparing this persuasive epistemic work with the scientific arguments that scientists (or student scientists) make to convince fellow scientists of newly discovered phenomena, demonstrates that the structure of the arguments depends on the purpose and audience of the argument. In this case, students are not writing a concluding argument with evidence from a confirmatory lab directed at their teacher or test-grader, but instead, they are writing a persuasive argument to a potential research funder with evidence and warrants from across the investigative processes. Students choose to use pieces of information that best serve the argument they are

trying to make. For the biodiversity group, they argued for the possibility of an important discovery that is relevant to the health of the park and that their initial investigation demonstrated it is possible to do this work. The pink slime group, also arguing with relevance in mind, argued for the need to extend their analysis with the claim that there is disconnect between Americans interests and corporations practices.

This analysis of the argument structures for student research groups highlights that they were thinking through the purpose, limitations and possibilities associated with the lines of investigation that had developed as they carried out investigations using the DNA barcoding technique of species identification. Students tailored their arguments for specific audiences using the available warrants for their claims depending on the outcomes of their investigations. Toulmin's microstructure for argumentation also affords a teasing out of places in which scientific practices were leveraged by students in their arguments and in which students were drawing from their experiences and interpretations to develop the argument. This is a valuable insight into the cascade of practices design theme that shows how the investigation and information practices are tightly linked to the argumentation practice.

### **Student Reflections on Practice-focused Instruction**

Near the end of the unit, we asked students, "Overall for the genetics unit, what did you like and what was most interesting?" Students talked about all portions of the unit, but overwhelmingly, they reported that portions of the DNA barcoding project were their favorite. Students appreciated being able to engage in real scientific work through the practices and their reflections fell into four high level categories of why they liked the DNA barcoding project: (a) Scientists do this work too and its recent scientific work, (e.g., "I liked all of the videos you showed us about using what we were doing in class in the real world. I liked it because these were real

scientists doing what we were doing;” (b) the work could contribute to a “what’s really in it” fraud-detection related discovery, (e.g., “I liked how we the students we in control of what we were doing. The most interesting part about this experiment was do see if our samples were not what they said they were;” (c) we got to do real scientific experiments and the process of DNA extraction was interesting (e.g., “I liked the DNA barcoding unit, even though my group didn’t get any DNA. It was cool to come up with our own experiment;” and (d) I never imagined I would get to do something like this or this is the most productive thing I’ve ever done in school (e.g., “The opportunities to continue our research is incredible”). Students recognize the change in instruction and perceive improvement in their learning environment when a class is shifted towards a PBL practice-focused instructional model. As was expected, students also provided feedback for improvement that included recommendations such as fewer activities and more time to go in depth, include pictures with the extraction protocol and spend more time explaining how it works, and make information (e.g., notes and completed activities) more accessible for students to revisit.

### **Discussion**

In this study, I described the ways in which learners engaged in several scientific practices—planning and carrying out investigations, obtaining, evaluating, and communicating information, and engaging in argument from evidence—during a contemporary biology project by examining practice performances through a social practice theory lens. In this analysis, I completed component analyses to access multiple perspectives of students’ performances. This work demonstrates the value in exploring the connections (or lack thereof) between social practices as a way to understand students’ engagement in scientific work. It begins to answer the questions:

what does it look like when students are performing scientific practices within a formal school context? And how do we account for practice performances?

In the comparison of students' scores of pre- and post-assessment items and students' reported engagement along five dimensions, we saw that sustain projects in PBL learning environments can support assessment demands placed on teachers and that students' immersion, buy-in, reported enjoyment, and desire to continue studying genetics played a possible role in students assessment scores. This finding is given additional context in the previous chapter when the scaling effort was impacted by teachers' need to devote time specifically to high stakes test preparation. There is still work to be done to figure out how to seamlessly connect the concepts present in contemporary biological work and those students are expected to know on their current state assessments. We are in a time of uncertainty as assessments for the Next Generation Science Standards begin to be developed. The NRC (2013) report on the development of assessments for NGSS recognizes that need to assess students' learning across the three dimensions (practices, crosscutting concepts, and core ideas) and that this assessment will look entirely different than current assessment in places. It remains to be seen how the adoption of NGSS will impact the uptake of innovative instructional models and their relationship with the new assessment systems.

The case studies, document analysis, and analysis of students' arguments build on each other to show that students' engagement in practices is variable across student groups and the performances of practices are instantiated in the contexts of performers who are pursuing a common goal and encounter interaction between practices across the four bundles of social practices at play: scientific practices, school practices, youth/everyday practices, and relevant social domain practices. Across the four component analyses, the goal was to identify

implications for “seeing” learning in practice and designing learning environments to support this learning. The Rouse (1996; 2007) inspired framework affords the tracing of learning in practice to demonstrate three points that seem to be productive for studying learning in practice.

*Relevant social domain practices play a role in learners’ seeing actionable outcomes from their scientific investigations.* The recognition of this fourth bundle of practice in the data led to reconceptualization of how students recognize meaning and action in their project work, and it points to a new dimension that is salient to the instructional design framework driving this work. We know from work in sociocultural learning and culturally responsive teaching and learning (e.g., Warren, et al., 2001) that designing learning environments in which students can make relevant connections to their everyday lives are valuable to students’ learning of science. However, in the initial analysis phases, it became clear that students were leveraging their knowledge of relevant social domain practices to support potential actions that could arise from their scientific investigations. Thus, they viewed their learning through participation in practice as having a potential meaningful and real outcome.

*Learning in practice involves substantial interaction between the bundles of practice in students’ lives and their learning environments.* Learning is a social phenomenon and in this case, science learning was situated in the context of students’ lives and positions in the world with access to information that allowed them to interrogate and make connections to the practices of organizations or domains outside of their direct local context. Penuel (in press) argues that learning should be conceptualized and in practice in which learning transforms learners’ possibility for action. He describes this an important goal for education research, writing:

education research is needed that focuses on how people use science and engineering *in* social practices as part of collective efforts to transform cultural and economic production. Drawing on social practice theory, I argue that learning inheres in such activities, not only because people access and make use of science knowledge and develop repertoires for participating in science and engineering practices, but also because participation in such activities transforms the ways that people imagine themselves and expands their possibilities for action. (Penuel, in press, p.2)

Using the information practice to obtain and evaluate information relevant to their investigations, students identified institutional and organizational practices that they could question or expose with an investigation using the technique of DNA barcoding. The intentional scaffolding of coordination between the investigation and information practice provided students with ways to identify and expand their possibilities of action beyond what is typically possible in formal school settings. This increased relevance in their learning environment was connected to students' opportunities to see across the four bundles and perceive links that support meaningful contributions to the work and their learning. Which means a performance of practice might look different across two different groups of learners in the same classroom because the goals, contexts, and interactions with other practices are also different. This stands in contrast to some perspectives on epistemic practices in the classroom that represent inquiry as independent and ordered scientific practices. .

*Performances of practices can and will look different across groups of learners.* From a social practice theory perspective, “local practice comes about in the encounters between people as they address and respond to each other while enacting cultural activities under conditions of

political-economic and cultural-historical conjuncture” (Holland & Lave, 2009, p. 3). Therefore, the qualities of practice performance need to be documented beyond a static, rubric-defined analysis of student work to a way of characterizing students’ performance of practices to account for the four bundles of practices that students interact and cross in their everyday lives. For example, in the analysis of group performance of argumentation via writing proposals for continued funding, each group used different evidence to support their claims depending on the available evidence (e.g., outcomes of other practices, connections to relevant social domains). This form of argumentation would not happen in a school setting with confirmatory laboratories focused on settled scientific knowledge. Students also tailored their arguments to consider the audience by framing the work in relation to its relevance to the possible action that could come from future work. This specific attention to audience is an important skill in science communication (Walters & Walters, 2011) and becomes a signature feature of deepening the learning and practice experience by making it more authentic to real world pursuits (Heath, 2012b).

Building learning environments for broadening participation in STEM means making the in-school science learning experiences of students more ambitious and authentic. This paper demonstrates that complicated, innovative, and contemporary project-based work can be accomplished and meaningful in formal learning settings. Curriculum design frameworks that look to support this work in formal settings should include opportunities and supports for students to experience connections between the bundles of practices that make up the settings of their lives and learning environments. This study indicates that students are able to productively engage in multiple related scientific practices that build on and inform each other. If these practices are designed around a common scientific technique, learning environments can be

designed so students are able to experience real scientific work with complex and uncertain circumstances that lend meaning and depth.

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## Chapter 4: Youth Explorations in Becoming a Scientist by Engaging in Contemporary Practices

In the previous two chapters I analyzed how teachers can be differentially supported in implementing scientific practice-focused instruction in their classrooms and how students subsequently engage in the instruction in ways that are meaningful to both their science learning and their participation in contemporary scientific pursuits. Student engagement in contemporary scientific practices means students are given control of interest-driven investigations over a number of weeks that support them in utilizing tools, techniques, and methods of the specific epistemic work of contemporary scientists. Students coordinated this scientific work across the social practices of their lives, employing scientific practices to gather information and design scientific investigations. These investigations had implications for real social domains that became apparent in students' performance of practices. This paper argues for students engagement in scientific practices as an identity-related strategy for supporting students in learning in practice that has bearing on who one is as an individual and who one sees herself becoming in the future.

### **Identity and Disciplinary Science Learning**

Learning is intertwined with identity, which I define as “the development of self in relation to others, through complex processes of identification with domains, and as evidenced by deepening participation in social practice” (Barron, et al., 2010). A leading goal as we develop curriculum that supports student participation in contemporary science is for students to develop science-linked identities. These connections between self and science may lead youth to pursue science-related careers, use science in decision making in their lives (especially around health and the environment), share their science expertise to support change in their communities, and/or participate in citizen science and engineering efforts throughout their lives (NRC, 2011;

NRC, 2012). Another goal is for students to leverage and develop existing identities as they learn through increasing participation in contemporary scientific practices. People and the contexts in which they live are constitutive of each other and learning is part of this interaction. Sociocultural theories discuss learning as changing participation in practices (Rogoff, 1997). Learning and identity are often closely related if not conceptualized in the same processes. Nasir & Hand (2008) find it necessary to distinguish between learning and identity and do so in the following way: learning is “shifts in the use of artifacts (both cultural and cognitive) for problem solving, sense making, or performance” and identity is practice-linked or “one viewing participation in the practice [at hand] as an integral part of who one is” (p. 44). Studying girls in science learning environments, Calabrese Barton & Brickhouse (2006) note, many forms of school science often engage girls in scientific practices that are irrelevant to communities outside of school or lack opportunities for girls to “form an identity with a trajectory toward new forms of participation in science and science-related communities” such as following lab procedures or memorizing vocabulary words (p. 224).

Nasir & Cooks (2009) argue that learning and identity are interrelated but distinct processes, and they define practice-linked identity as “one viewing participation in the practice as an integral part of who one is” (p.44). Both self-realization and social recognition are crucial to identity development processes. This paper focuses on the social influences on self and the presentation and influence of self in social situations related to participation in contemporary scientific practices. This recognition work is important to the relationship to the scientific practices and stabilization of identities in ways that promote credibility of and devote resources to students’ identities in particular contexts (Carlone & Johnson, 2007; Holland, Lacioicotte, Skinner, & Cain, 1998).

Learning is changing participation in these cultural practices or figured worlds and can be conceptualized as the acquisition of specialized repertoires of cultural practice (Nasir, Rosebery, Warren, & Lee, 2006). Researching learning from this perspective requires understanding individual roles and positions in coordinated activity, how people participate in this activity, and how their participation changes from peripheral participation to more central participation (Rogoff, 1997; Lave & Wenger, 1991). In addition, Penuel (in press) argues that this model is more complex when moving from peripheral participant in apprenticeship-like ways because contemporary professions are ever changing and students must learn to change and adapt their practices as communities of practice change. Positions in activity influence identity and learning in relation to these evolving cultural practices.

Positioning theory is useful for describing the rights and responsibilities for an individual to perform an action, in other words, that an individual's position in certain context is constructed discursively and socially. Positioning theory accounts for the multiple selves of a person that are manifest in the context of situated activity by studying how they are "taken up and laid down, ascribed and appropriated, refused and defended in the fine grain of the encounters of daily lives" (Harré, 2008, p. 29). Scholars have looked to positioning theory to describe the "...cluster of rights and duties to perform certain actions..." (Harré & Moghaddam, 2003, p. 5), in other words, that an individual's position in a network is constructed discursively and socially. For Holland et al. (1998), positionality calls attention to a person's action has a particular place in the social context that is related to all the possible activity in that context. Identity can be understood as constituted in the positions people take up or refuse in differing social timescales from interactional moments to months to years.

## **Characteristics of Settings Contribute to Practice-Linked Identity**

Comparing a basketball team and a high school math class, Nasir & Hand (2008) identify aspects of the two contexts that support development of practice-linked identity and engagement. Due to the inherent connection between self and practice in this definition, a person is more likely to be engaged in practices that she feels close to. Sense of responsibility is also evident in the three aspects of settings that Nasir & Hand (2008) demonstrate as important for understanding engagement and identification: (a) access to the domain, (b) integral roles and accountability, and (c) opportunities to engage in self-expression, to make a contribution, and to feel valued and competent. Engagement was evident across all three dimensions in the practices of basketball, but engagement was stifled in the math classroom where students had less access to the three dimensions. Through basketball's participation structures, players could connect with practices with their selves. Therefore, Nasir & Hand (2008), "characterize practice-linked identities as reflecting both the contours of a practice and the particular ways in which an individual integrates these into the person he or she is becoming" (p. 175). Affordances of settings to support practice-linked identity demonstrate how the learning settings can connect to participants and "extend beyond learning (though learning is certainly critical) to the very definition of who one is and who one is in the process of becoming through participation" (p. 176). Within the context of the project-based curricular units in this study, the identity support dimensions show up in the instantiation of design principles within the learning environments. Projects were designed to give students access to contemporary intellectual spaces and methodological tools of biological domains that demanded rigorous attention to detail and accountability. This led to interactions with experts where students could situate their own work within the professional

domain in a way that communicated the value and contribution of their efforts, often in ways that were tied to the personal interests of the youth.

### **Interest and Identity in Contemporary Science Investigations**

In Chapter 3, we saw how students' engagement in scientific practices in contemporary investigations is a complex interaction between the of practices in students lives and how through varied participation in practices students come to write about and recognize how contemporary investigations can give them leverage for potential action outside of the school setting. The question remains, how in the varying nexuses of social practices that make up students' contemporary scientific practice productions do students become to see themselves in the practices of science as people who can make meaningful contributions to the scientific work and who are interested in continue to learn about careers and learning trajectories into STEM. What are the micro-processes in everyday participation that lead up to becoming in practice in the life sciences? How do students experience these interest and identity development processes?

The goal of this chapter is to analyze moments of interaction related to scientific practice that relate to and advance learners' trajectories towards socially recognized and networked participants in disciplinary work. In this study, curricular units lasted from six to eight weeks and therefore, there are limitations on the claims that can be made about student development of identities, however, I can make claims about student's perceived and reported shifts that can contribute to their stabilization of practice-linked identities participate in various contemporary scientific practices—which I take to be way that identification unfolds in social context (Wortham, 2009). The theoretical framework and analysis tools allow for situating students' interactions in the broader contexts of their lives as well as in the context of what we know from

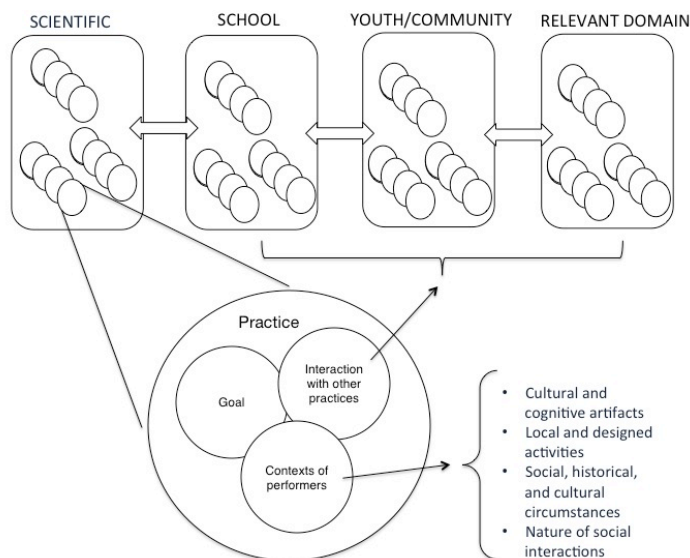
research about how students' practice-linked identities are influenced and developed through interaction with others in social practices.

### **Theoretical Framework**

To understand the how engagement in contemporary scientific practices can support or hinder the development of practice-linked interested and identities, I developed a theoretical framework that layers two related theoretical ideas: (a) a definition of practice from a social practices theory perspective; and (b) aspects of settings and social interaction for supporting the development of practice-linked identities that can help to characterize how contexts of performers influence participation in practices. First, I describe the two sets of concepts and then how they interact with each other to act as a framework for data analysis.

Taking scientific practices as social practices demands seeing science practices in the social and material nexus of the other relevant practices of participants and where these practices align and misalign. People live and participate in multiple diverse contexts and these contexts are socially and materially arranged by the social actors to allow for particular practices to occur within them. Taken together, the contexts are separated or linked from other practices in a “comprehensive structural nexus of social practice” (Dreier, 2009, p. 196). The framework views students' contexts of practices as situated within four sets of partially aligned social practices present in the classroom learning environment: (a) contemporary professional scientific practices (e.g., planning and conducting a scientific investigation); (b) school practices (e.g., participating in mandated, orchestrated assessments); (c) youth and community practices (e.g., the daily practices of the youth and/or local community); and (d) the practices of relevant social domains (e.g., societal arenas of activity that make use of the specific practices).

Practices are not static actions of humans, for Rouse (1996) practices are not “the doings of human agents but... the meaningful situations within which those doings can be significant” (p. 38). These situations or configurations have specific features that allow them to be documented as practices. According to Rouse (2007), practices should have three key features: (a) they are bounded by the ways in which performances of practice interact; (b) there is something “at issue” and “at stake” in the outcome of the practice; and (c) performances of practice are situated in the circumstances of the performers.



*Figure 1.* General configurations and influencers of social practices.

Seeing interest and identity development in the interactional moments of student participation in contemporary scientific practices necessitates moving a level deeper into this framework to describe the ways in which the social and material contexts of performers support or hinder practice-linked identity development. I focus on the specific characteristics of the settings that do or do not support practice-linked identity development according to Nasir and Hand (2008): access to the practices of the domain, roles and accountability within those practices, and space to make contributions. Learning environments can be supportive of moments that lead to

stabilization of practice-linked identity development and the interactions between the epistemic practices and the contexts of students' lives can create situations that produce identity resources, which become apparent in the configurations of settings and the interactional moments of participants. Identity resources are defined by Nasir and Cooks (2009) as material equipment, techniques, phenomena of the natural work), relational (membership, relationships, access to roles), ideational (seeing oneself in practice). Together, this framework allows for locating practice-linked identity development within a frame of normative social practices in a way that highlights the features of learning environments — aspects of settings and practice-linked identity resources —that make practice-linked identities and identity shifts available to learners.

Over time practice-linked interests and –identities can stabilize. Building on ethnographies of science learning and ethnography, Figure 2 depicts a theoretical model that begins to describe the pieces of identity development in play as practice-linked interests and identities stabilized over time.

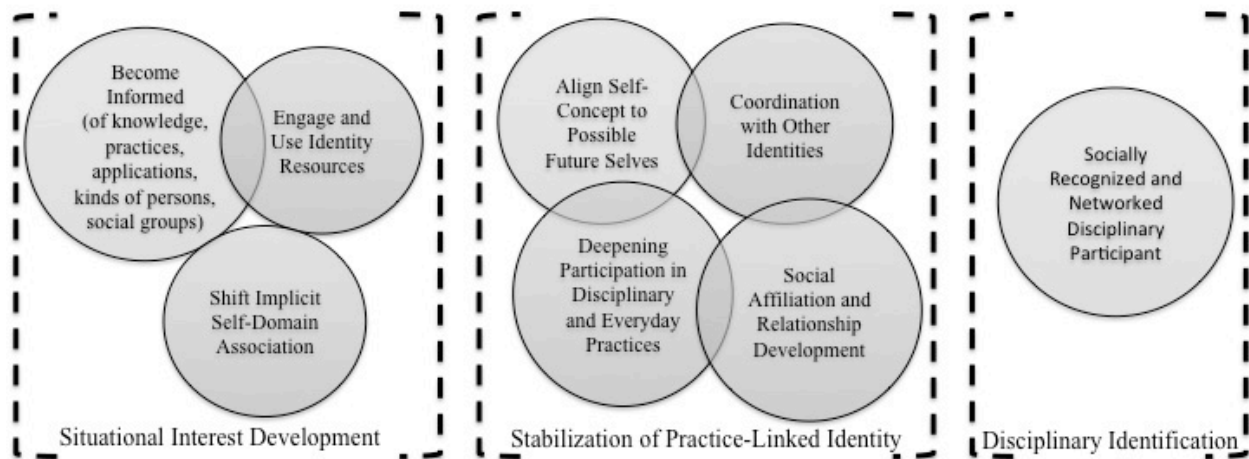


Figure 2. Stabilization model with three phases of practice-linked identification (Bell, in preparation).

In this model, stabilization occurs as learners begin to access a disciplinary network and gain recognition socially for their position within the network. First, a learner becomes informed

about a specific scientific domain including the types of knowledge, practices, and applications of that domain. Next, through deepening participation in disciplinary and everyday practices and leveraging the linkages between those practices, learners may gain access to social recognition (Erickson, 1968; Carlone & Johnson, 2007; Holland, Lacioicotte, Skinner, & Cain, 1998) and relational and/or ideational resources that support the stabilization of their practice-linked identity by giving them opportunities to take up the identities in the context of social practice. This happens in relation to the multiple other fluid identities that learners have in place at any given moment. Finally, the outcome phase of the model is a stabilized, although ever shifting, practice-linked identity where the person is socially recognized by and affiliated with a disciplinary community of practice or a learning environment designed to network students into disciplinary communities. This is a long-term developmental process with many instances of overlap between the phases of identification across a person's life. Scientific literacy is a form of science identification all people should have opportunities to develop over their lives in ways that serve them.

### **Research Questions**

A focus on learning and becoming in practice to form or stabilize practice-linked interests and identities comes from this conceptual framework for analyzing students' participation in contemporary science project-based learning environments. The following two research questions guided this analysis:

- What role does leveraging current identities/interests have in the link between practice-link identity and possible future identities within curriculum implementation?
- How do identity resources in curriculum that show up in the nexus of social practice facilitate (or not) this identity stabilization?

### **The Intervention, Settings and Participants**

The educational intervention consists of a yearlong introductory Biology course composed of five project-based instructional units delivered on a social media technology platform. The curriculum approach sought to engage students in contemporary science focused PBL projects that were structured to give students space to take on interest-driven investigations. The curricular materials were delivered on an online platform that also served as a place for students to conduct discussions, learn about each others' interests, save notes and brainstorm, and interact with disciplinary professionals. These disciplinary experts were tapped because of expertise and careers topically related to the unit and they interacted with students on the online platforms to give them feedback on their project work, answer questions related to the topics under study or their field and career, and to act as an audience for students' culminating products. Across the five curriculum units, students participated in investigations that spanned across types of scientific work and included fieldwork, bench work and computational work. During the beginning stages of course development (2010-2012), units were piloted individually in a collaborative co-teaching model with researchers present in the classroom each day.

This analysis focused on case studies and vignettes from data from across the initial pilots of two units. In the first unit, the DNA barcoding project that was embedded within the eight-week long genetics unit and included a citizen science protein folding game called Foldit. Citizen science is a widespread effort to engage the public in various aspects of scientific efforts. Often these efforts include collaboration between the public and scientists on data collection, analysis and/or reporting. For example, citizens might volunteer to help track a certain bird population and with increased human capital, scientists have access to more data about those birds and their behavior patterns. Foldit is an example of a successful citizen science effort. In 2011, Foldit players solved protein shape problem that had stumped scientists for 15 years

([http://www.huffingtonpost.com/2011/09/19/aids-protein-decoded-gamers\\_n\\_970113.html](http://www.huffingtonpost.com/2011/09/19/aids-protein-decoded-gamers_n_970113.html)). In the second unit, the modeling infectious disease transmission project that was embedded within a six-week long unit on the micro and macro aspects of infectious diseases. Both projects had similar characteristics, students wrote research design plans outlining their interest-driven investigations supported by background research, then students carried out the investigation using contemporary scientific tools and techniques appropriate for the investigation, and finally, students produced authentic scientific written artifacts to communicate the conclusions and open questions about their work. Foldit was an additional activity within the genetics unit where students learned through tutorials and then competed on contest protein to design solutions for a protein related to creating pluripotent stem cells. These enactments took place in two different schools: Viking High School and Innovation High School (all school, student, and teacher names are pseudonyms).

**Viking High School.** Leah Bricker and I enacted the second iteration of the genetics unit at Viking High School in five biology classes taught by one teacher. The school is a public, urban high school in the Pacific Northwest. It houses a biotechnology academy; however, the introductory biology classes were not part of the academy. The teacher, Mr. Lewis, was a first-year teacher who completed his student teaching in a biology/AP biology classroom. This was the UW team's first partnership with Mr. Lewis and Viking High School.

**Innovation High School.** Leah Bricker and I enacted the first iteration of the genetics unit and an iteration of the infectious disease unit at Innovation High School. The school is a public STEM magnet school with a specific career and discipline focus in the Pacific Northwest. The school has long standing connections with many of the large industries in the area. We worked with two teachers at the school in this study: Mrs. White and Mrs. Cannon. Mrs. White

taught biology and Mrs. Cannon taught physical science; both teachers taught a health course. This enactment site arose from an ongoing previous partnership with the school and teachers.

### **Methods and Data**

I analyzed the configurations of the learning environments that occurred when students were asked to engage with scientific practices in the context of existing social practices. Analysis traced how interactional moments were constructed in the learning environments as students' engage in cultural learning pathways throughout a curricular unit or subset of a curricular unit (e.g., Bell, Tzou, Bricker, & Baines, 2012).

An initial round of coding revealed instances of interest or identity related talk specifically in the context of contemporary scientific practices. From there, case studies were identified based on the students in focal groups pre-selected during data collection with the most complete data sets and the case studies were constructed using narratives and patterns and themes of practice-linked interest and identity development arose from fieldnotes, document analysis, interviews, and students' online participation including unit-related surveys through open coding (Emerson, Fretz, & Shaw, 1995; Miles & Huberman, 1995; Strauss & Corbin, 1998). In addition, I used interaction analysis to analyze video of situated activity systems in the classroom to describe the ever-changing contexts where embodied action takes place in relation to learning and identification (Jordan & Henderson, 1995; Goodwin, 2000; Nasir & Cooks, 2009). This included coding for social positioning moves within interactions (e.g., Holland et al., 1998) and identity resources in both interactional moments and students' work and interviews (e.g., Nasir & Cooks, 2009). In addition, I coded for moments of students' participation in the embodied practices of science, students' affective engagement in interactional moments, and students future projections of self.

*Data Corpus.* The data corpus from Viking High School for the genetics unit enactment includes: student work and class performance data (n=71), student artifacts from 12 groups (which included 4 students per group), instructional records (lesson plans and daily reflections), one student focus group, and interviews with four students and one teacher. In addition, across all five class periods, the corpus includes about 16 hours of video data focused primarily on the DNA barcoding laboratory work and students' Foldit game play.

The data corpus from Innovation High School includes data from two enactments. First, the enactment of the genetics unit was a shortened unit focused mainly on Foldit. Related to this enactment, the data includes: student work and class performance data (n=76), instructional records (lesson plans and daily reflections), and seven hours of video related to Foldit game play. Second, for the infectious disease enactment, the data includes: student work and class performance data (n=46), instructional records (lesson plans and daily reflections), and video of students working on their computational models of infectious disease spread.

Two main case studies emerged from analysis of selected data specifically focused on students' contemporary scientific work. The comparative case analysis allows for seeing how different features of learning environments can support students "unlearning" about how science works in the real world that then leads to learning that can change how one sees himself in relation to scientific practices. Each case is followed with shorted supporting vignettes that contained similar or contrasting themes to the larger case. First, I discuss the case of Erik, a tenth grader from Viking High School.

**Case Study: Erik — "I realize how interesting it is to take stuff you don't know about and experiment with it"**

This case study attempts to demonstrate the social and contextual influences in play when learning environments allow students to try on a new scientific practice-linked identity through

learning and unlearning about the domain and thus transforming views of oneself and possibilities for future action related to the domain (Penuel, in press).

Erik was a student at Viking High School. This high school had a biotechnology program but all students in the biology classes we worked with were in the standard science track in their school. Near the beginning of the unit, Erik expressed in his online profile that he participated in cross country, track, and soccer and had a career goal of studying engineering. Related to that goal, he wrote, “I like science because I like being able to apply mathematical logic and concepts to my work. I like physics and mechanical sciences.” Erik already had career ambitions and ideas related to STEM but they were not related to biology. At Viking high school, we spent eight weeks in the Mr. Lewis’ biology classroom enacting the genetics unit with a DNA barcoding project in all five of his biology classes. The project was the main focus on the unit but it was embedded within other activities designed to facilitate students’ understanding of genetics concepts. We introduced the project by describing the current scientific research underway using the DNA barcoding technique. These examples included scientists using DNA barcoding to identify mislabeled foods, to catch illegally traded animal products, and for surveying biodiversity in a given area. This was all in the context of helping students understand how the structure and function of DNA allows for this comparison across species. In this DNA barcoding project, students were supported to use what they knew about their local contexts, their own interests, and the reasons why DNA barcoding can be used to compare DNA between species to design and carry out an investigation on a species identification issue of their choice. The detailed analysis of Erik, David, Kelly, and Jayna’s engagement in the scientific practices that facilitated their participation in the project was highlighted in Chapter 3.

Three episodes of activity demonstrate how Erik's opportunities for developing a practice-linked identity related to biological sciences and scientific practices in general built up over the eight week unit: (a) learning about a DNA extraction kit for processed foods, (b) taking up the role of group pipettor, and (c) reflections on the DNA barcoding laboratory experience. Episodes were chosen because they represented moments across time as well as insights into participation in specific scientific practices and students reflections "unlearning" and practice-linked identity stabilization. Overall, the project was broken up into three major parts: (a) authoring a research design plan and background research, (b) conducting DNA barcoding process laboratories, and (c) writing a proposal for continued funding of the research (as a culminating performance). Parts one and three were scientific practices centered around student-authored written artifacts and part two involved a series of laboratory bench-work that students conducted to extract, amplify, and sequence the DNA in their samples.

**Episode 1: From synthetic marijuana to herbal cough drops.** In the first episode, *Learning about a DNA barcoding kit for processed foods*, Erik — the self-positioned leader in his group a move supported by his group members— David, Jayna, and Kelly wanted an innovative and meaningful investigation. Reflecting back on the process, Erik said, "We took a long time to come up with a research question that was not on the list and not too similar to other groups' projects." They were trying to take full advantage of the interest-driven design feature of the project work—something that is not usually available to students in science classes. They started by looking at a list of options for research and then building on an example of a study of Tobacco, the group decided they wanted to investigate the plants used in synthetic marijuana. The group was really excited about this project as were the teachers and researchers who were thrilled that the students wanted to work at the boundaries of what has been studied. Recognizing

the potential issue with bringing the drug on campus, the teacher explored the option with school administrators who subsequently vetoed the idea. The team was upset and wrote that their idea had been “shut down.”<sup>1</sup> Erik took the lead on the follow up brainstorming process to quickly determine a new idea for them to pursue. Eventually they settled on a study to investigate the plant ingredients in herbal cough drops, which are not well regulated and could be prone to fraud or public health risks. As Erik put it in an interview at the end of the unit, “...the idea behind this is that... a lot of people have allergies [to] specific plants and there’s very very loose regulations across the nation for cough drops. So for us...we were hoping to get the DNA out and see if the ingredients were actually what was listed.” Erik and his group identified a species identification problem that Erik felt was important from a human interest point of view and the results could be used to inform people about potential risks and unlisted ingredients in a commonly used product. However, they were all a bit leery as to whether or not it was possible to extract DNA from something as processed as cough drops.

Next, to proceed with the investigation the group jointly constructed a research design plan supported by background research that would guide their investigation. Each student was responsible for completing a literature review on a topic related to the investigation. Erik — given the worry that it would be difficult to extract DNA from cough drops — chose to research current techniques for extracting DNA from processed foods. He confirmed that extracting useable DNA from foods and pharmaceuticals can be quite difficult but through his research, Erik found a kit that was specifically designed to extract DNA from foods and claimed to have been tested on pharmaceuticals. When asked to reflect on the project at this juncture, he was concerned that he needed more information from the educators about the process we would use

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<sup>1</sup> This tension between student interest and school policy was explored in the analysis of Chapter 3.

in class to see how it compared to the one he found. He wrote, “I think the project is a very unique experiment and I really look forward to extracting the DNA. I think it would be helpful if we were given a greater overview on how we're going to extract the DNA so that while doing research we could have a better understanding about how our procedure differs or relates to that which I was reading.” Through Erik’s scaffolded background research experience, he was able to find a material resource that grounded the group’s investigation, and it served to lend support for his own recognition as a developing expert in the work. The material resource also facilitated the social recognition of his growing expertise by the others in his group and the educators in the classroom. He was allowed to run with specific aspects of the investigative work specifically related to the DNA extraction and he took the lead on written aspects of the work related to the material resource. This particular material resource was a key actor in Erik’s entire learning experience across the project work. I also argue by finding this resource, Erik’s ideas about himself as someone who located a solution to a potential problem in the scientific practice — not being able to extract DNA — began to develop and shaped how he participated in the rest of the unit. As they completed the unit’s assignments by writing a proposal for continued funding, Erik wrote the main argument portion of their joint document. Asked to summarize his proposal work, he said:

In my funding proposal, I’m saying that, um, we basically, we found a kit that, through our background research that would be perfect for taking DNA out of processed foods. But unfortunately, our class, we didn’t have enough money to buy that kit so we had to use a regular kit. And that’s why, we want to work with the University to hopefully get that kit that is specifically made to take the DNA out of processed foods.

Positioning himself and the work of their group as valuable, Erik's case shows how the material resources associated with a contemporary scientific investigation can be linked to seeing the value in his work and providing ideational resources as someone who, with continued funding, can solve a scientific problem. The group approached this classroom science project as authentic scientific work that should be taken seriously. It allowed for Erik to be positioned as a scientist through his efforts to improve the experiment and by the recognition of others who saw him deeply engaging in the research design practice.

**Episode 2: Pipettor role conveys leadership.** Episode 2, *Taking up the role of group pipettor*, describes how Erik's leadership role continues into the week-long series of wet labs that occurs in the middle of the unit. There are two people that position him within a leadership role. He assumes this leadership role partially because Mr. Lewis appoints him the group's pipettor, and he attends a special training session only for one member of each group to learn how to do that part of the work. The rationale behind selecting one person from each group to specialize was a logistical decision; Mr. Lewis needed to do the training quickly as a side activity due to time constraints. While roles are quite common in classroom practice, this particular role was vital to the group's success in the wet laboratory and therefore it came with a great access to materials than other members of the group were able to gain. Ultimately, this practical constraint that necessitated training only one pipettor per group had an unintended influence on access to specialized practices for some. Erik's positioning as a leader in the work was also partially due to David, another student in the group, enrolling him into an instructional role by looking to David to answer his questions about pipette use. Having sole expertise on how to work the pipettes, Erik had access to and control over the most used scientific tool in the laboratory work to be undertaken. This material resource directly supported his participation in the embodied scientific

practices of the laboratory work thus supporting his learning and uptake of a new view of how science is done. When asked at the end of the unit what was most exciting about it, Erik replied:

I think probably the most exciting part is being able to use all the technological equipment and, you know, the centrifuges and the electrophoresis to test our DNA. A lot of, up until now, all my other projects we had ever done, science projects, you know, in-class labs, were always these simple labs where you're just, you know, growing plants or something. Now, all of a sudden, we're using equipment, we're using high-tech pipettes, you know, to actually extract DNA or things that we can't see, and I think that's the, probably the coolest part.

Erik's reflection shows how the material resources available to engage in the contemporary laboratory practices involved in the unit were in contrast to his previous experiences with labs and projects in science class. The contemporary science focused project, which necessitated contemporary scientific tools, allowed him to debunk school science in a way that helped him to begin to revise his relationship with the domain. The embodied scientific work of using instruments allowed Erik access to begin to see the kinds of persons who do scientific work are not people who do confirmatory labs or who grow plants for observation alone—to one focused on using specialized techniques and equipment to study a fundamental structure in biology that cannot be seen. And he shifted to see scientific knowledge as embodied in practices of doing the work. The pipetting work served as a relational resource for Erik's relationship with the scientific work, which stabilized as he worked through the project. In Episode 2, he was beginning to see what Lynch described when he wrote

we should forget 'knowledge' as an adequate way of formulating the entire 'content' of a science. Much of what goes under the heading of 'knowledge' in science studies can be

decomposed into embodied practices of handling instruments, making experiments work, and presenting arguments in texts or demonstrations. (Lynch, 1997, p. 310)

There is a clear equity argument to be made that all students should have access to specialized, resource-rich science learning experiences that broaden access to participation in science practices in the classrooms to increase students' chances of both STEM careers and productive use of science in their everyday lives by stabilizing their science-related identities. This highlights the clear material resource inequality issues associated with contemporary education.<sup>2</sup>

As the pipettor in his group, Erik also controlled access to the pipettes. Jayna and Kelly monitored the other materials, mainly tubes, filters, and reagents, and David read through the protocol and spent a fair amount of time trying to understand the details within each step of the work. There were times during their laboratory work that it was clear that David was at the disengaged and other times where he would dig into the minute details around the best way to carry out a step in the protocol. All groups were working through complex scientific protocols that had been lightly edited and formatted for classroom use. In the following exchange while the group waits for their samples to incubate, Erik, Jayna, and Kelly try to mediate and control David's access to materials, which slowly shifts into an instructional moment where Erik helps David learn to use the pipette. It began as all four students came back around the table from taking their samples to the water bath to incubate. They were wearing science lab aprons and goggles. David was eating a lollipop, which sometimes made him difficult to understand in the video and further signals his playful participation in this interaction.

1 David: (picking up a pipette) Hey can I mess with this? I'm going to. I'm gonna be a scientist.

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<sup>2</sup> The broader project attempts to do just this—to bring contemporary science into a diverse variety of schools (see Chapter 2 for more details on this work).

2. Erik: I wouldn't, I wouldn't.
- 3 Kelly: No, don't use it.
- 4 Jayna: Yeah, don't use that stuff (referring to a bottle of buffer David picked up)
- 5 David: Oh, why not? (looks carefully at the bottle)
- 6 Jayna: Because it's valuable.
- 7 David: Hey, hey, hey. (in response to Erik picking up the pipette and checking what volume it is currently set to, Erik hands the pipette back to David)
- 8 Erik: Just make sure you don't turn the numbers while you are working.
- 9 David: Alright.

Erik walks away to go check on the samples that are incubating.

In line 1, David positioned himself in a immediate-future statement, "I'm gonna be a scientist." He implied — partially joking — that through using the pipette, he would be a scientist, which implies a distance from participation and identification he had been experience in the group. This was also a self-repositioning move after a short absence from participating in the group. This was a general habit of his across the unit where he would shift from intense levels of engagement to levels of complete disengagement within a class period. Immediately after, in lines 2, 3, and 4, his three group mates discouraged first his use of the buffer he wanted to pipette because he wanted to use the buffer to practice outside of the use in their laboratory work. Affectively the talk was part serious, part playful. Erik, Kelly, and Jayna were not angry with David and their tone of voice indicated a "he will do what he will do" attitude, but at the same time they were trying preserve the materials they need for the laboratory. In line 7, Erik picked up the pipette, which caused David to react and in effect ask for it back. Erik was checking to see what volume it was set to and in line 8 he asked David to not turn the numbers.

At this point, he walked away to check on the samples. Earlier, Erik had set the pipette 130 microliters per the protocol in anticipation of the next step. Erik's move in lines 7 and 8 help to solidify his position as the pipettor in the group. This point is accepted by David, and the two begin an instructional exchange over the following minutes where Erik teaches David how to use the pipette by hanging nearby to answer his questions. The long wait time during some portions of the protocol, which is customary of scientific work, led to this lag time where students prepared for the next step, set up equipment, or explored the materials on their own. The exchange continued:

10 David: Can I see one of those please. (said to Jayna pointing to the pipette tips)

11 Jayna: No, you can't...no.

12 David: You got to be my science assistant.

13 Jayna: Noooo, you are just going to like waste them.

14 David: No, I just wanna use one of those. (points to the pipette tips again)

15 Kelly: I don't think this is the right one, that's the the right one. (points to the other jar of pipette tips).

16 David: Oh, okkk. Well you are just being mean to me (picks up a pipette tip from the jar Kelly recommended).

17 Jayna: I'm not being mean to you.

During lines 10-17, Jayna was trying to prohibit action but the tone was still light. Throughout, Jayne was working with Kelly to label tubes to get ready for the next steps. After the initial denial in line 11, David made a positioning bid to Jayna, "You got to be my science assistant." This further affirms his idea of science as sometimes being deeply connected to the material practices of the work, in this case pipetting as well as another partial joke move to establish

authority over Jayna. It also shows how David's more restricted access to the material resources makes the practice-linked identity more difficult to take up. Jayna continued to restrict access in to materials by not physically handing him the particular pipette tip he asked for. However, in line 15, Kelly jumped in to say the other jar of tips was actually the correct one and David took a tip from that jar. I interpret David in Line 16 as partially playful banter, but it is understandable that he see their actions in a negative light given the difficulty he experienced in accessing material resources for "messing around" in this interaction. He started off the encounter in a playful manner and positioned himself as "messing" with the pipette to get experience using it, but he wasn't demanding to be in the pipettor role. Jayna and David smiled throughout lines 10-17 and both used a tone of voice that sounded on the edge of laughter. In the following minute, David continued to "mess with" the pipette and Jayna and Kelly labeled tubes.

16 David: (laughs, smiles, looks up at Erik as he comes back to the table, continues to pipette, Erik then watches as David uses the pipette)

17 Erik: No, no, no, no, no, no (responding to David's movement of the pipette).

18 Kelly: Wait, don't we need those (looking at David)?

19 David: I, this is for one from them (points to the other table, 3 sec. pause) nooooo a big deal. (he had borrowed a tube from another group that had extra so as to not use up all his groups' resources).

(Inaudible conversation between Kelly and Jayna, Erik continues to monitor David's pipette use and stand ready to answer and questions.)

20 David: (to ERIK) what does this part do right here? (points to the arm of the pipette responsible for ejecting the tips)

21 Erik: (2 sec. moves hand to pipette and demonstrates) push

- 22 David: Oh, oh, oh, ohhhhh alright, this is fun (response to the pipette tip flying off the end when Erik showed him the eject button, he repeats this move again before picking up the tube to continue using it, he does this for about 30 seconds before KVH arrives).
- 23 KVH: What do you guys got going on? (then to David) Are you just playing? Ok, that's fine. (inaudible – offers to get a beaker of water for him to practice with)
- 24 David: For me? (looking at KVH) Please. Thank you. (Pause) Oh look what we got!
- 25 Erik: Yeah, see what happens? (moves hand to pipette to emphasize what happens when David makes the adjustment to the pipette.)

This segment began as David looked at Erik in what could be construed as asking for approval or guidance, or just double checking to make sure it is alright for him to continue to mess around. Which prompted Erik in line 17 to give immediate feedback about the way he was using the pipette. Kelly then recognized a tube Erik was using as one they needed in the next steps in the protocol. David has borrowed a tube from another table with extra. This was a continuation of him figuring out ways to access resources and bring them into his play act of being a scientist without making a huge disruption to his group. In line 19 he pointed this out to Kelly by saying, “not a big deal.” Erik watched David and looked over the protocol steps so he knew exactly what David was referring to in line 20, “what does this part do right here?” Erik responded by demonstrating, and David was excited by the pipette tip ejection process, which he repeated a few times before going back to the pipetting process. He was exploring all aspects and mechanisms of the tool through a combination of play and instructional interactions with Erik.

As I came to check in with the group in line 23, I recognized David was trying out pipetting and offered additional resources for his “play.” This move furthered sanctioned David’s messing around or playing as a legitimate use of time at that time. Finally, in lines 24 and 25, Erik responded to David’s excited about seeing a new feature by demonstrating what happened if he made an adjustment to the tool.

During the times of heavy activity, David wanted to understand each step of the process and therefore had trouble following along at the speed with which his group worked. However, the incubation wait time led to this instructional moment interaction where David could learn from Erik about how to use the pipette. Later in the class period, David sat alone at the table, reviewing the protocol, which turned into a lengthy discussion with Mr. Lewis about tricks to transfer liquid after centrifuging. Erik and David’s access to the material resources varied widely due to several positioning moments across this interaction. Erik’s position as the pipettor in the group meant he had access to the most material resources and therefore the practice-linked identity related to this work was made most available to him. In this set of interactional turns, David made a bid for participation in which he decided he would learn to use the equipment and “be a scientist” as he was doing so. His group reluctantly supported the bid with much effort on his part and by the end of the interaction, he had a good sense of how the pipette worked and he has amassed a collection of materials with which he could mess around with thus he built up his own space and relationship to the practices with instructional support from Erik. The extra time associated with the lab work opened up space for this informal teaching, learning, and identification work to unfold. It is in contrast to typical school practice where such messing around would be minimized. Through the study of the new media practices of youth, Ito et al. (2010), found that the practices of youth increased in sophistication from hanging out, to messing

around, to geeking out. In the highest level of participation, youth were producing new media for sharing online. In classrooms, contemporary scientific work has the potential to make room for gaining sophistication in participation through the unstructured wait times.

To summarize the groups' progress so far in the narrative, I utilize Erik's reflection on the investigation and summarizes other salient aspects of the DNA extraction work:

Well, that's the thing. We, [laugh] when we took the, we extracted DNA, or we thought we took DNA out and we ran it through electrophoresis. We found there was no DNA, unfortunately. And that was kind of what we had expected. 'Cause when we were doing our research, we, or I found, when I was doing my research for the group, the protocol for extracting DNA and for the PCR for processed foods, like what we're using, was much more complex for processed foods than for just regular plants. And the kit that we had or that the class had and that, um, our teachers brought in was only for the generic, um, yeah, the generic plants, fungi. And so, we were, we feared when we working that the processed food, since the cough drops have been processed so much, that it would not, um, that we wouldn't be able to get DNA out.

Referring back to the material resource in Episode 1, Erik explained why they did not get DNA from the laboratory work and how that was his expected result. In the final episode, I analyze Erik's reflections on his engagement in the contemporary scientific practices of DNA barcoding.

**Episode 3: I'm not looking forward to going back to regular class.** In Episode 3, *reflections on the DNA barcoding experience*, Erik's survey and interview responses make up a series of reflections on the work, his position in the work, and how the material, relational, and ideational identity resources in contemporary scientific practices-focused work shifted his scientific

practice-linked identity. Early on in the unit, Mr. Lewis sent us the text of an email from Erik's parents thanking him for inspiring Erik:

Erik has been enjoying class quite a bit lately. Based on what he tells us, it sounds like that the pilot program with the UW has been quite successful and is very interesting! He was very enthusiastic telling us how they're learning directly about the latest accomplishment by researchers in the field and how great it is to have access to all the data. Thanks for making class so inspiring!

In this email text it is interesting to see how Erik's parents constructed his experience as he related it to them. They note the work as contemporary and based on what researchers in the field are working on and he also notes his access to data used by scientists. He said in his interview,

being able to work on something, being able to have our notebooks online so that, at home, if I needed to work off something, I could, I could even show my parents links of oh, look what we're doing in class now.

At the end of the unit, he had a similar reflection about how interacting with experts allowed him to "hear the direct feedback of scientists who are, whose job is to what we're doing right now."

In the context of Erik's identification process, his statement can easily be interpreted as a relational resource positioning statement showing how Erik sees his work directly parallel to that of the disciplinary experts.

Erik reflected at the end of the unit on his entire experience throughout the unit, and his overall assessment was, "I feel that I have been extremely lucky to be in this class that does this project." In Episode 1 and Episode 2, Erik began recognize the difference between science class as he had previously experienced it and science class as designed in this intervention with students participating in contemporary scientific work. By the end of the unit, he felt his

understanding of scientific practices and in turn the relationship between scientific practices and his own identity has both shifted in a positive way that could affect his possible future selves.

When asked if he found the unit inspiring, he said:

Yeah, this unit has inspired me. I'd, up at, before now, you know, I've always been, oh well, you know, science is kinda fun, not really. It's too much note taking. I never really liked it. I was always interested more in aviation. And now, doing this, all of a sudden, I realize, the actual, you know, how interesting it is to take stuff you don't know about and experiment with it and then get results back and then try again and keep going at it. It just, all of a sudden, it seems like it just opened up a bunch of doors for me.

Erik's realization in this interview quote is a clear move of prolepsis, or an imagined future identity based on his recent experience (Cole, 1998). Through his engagement in the scientific practices, an iterative experience of creativity and problem solving, he found a practice-linked identity available to take up and explore. This raises a question of values: Is this kind of profound self-realization by Erik, and to a degree, David, Julie, and the other group, something we can afford not to do? Can we continue to avoid disrupting the practices of normal school science while missing this kind of effect on how students understand themselves in relation to their possible futures? This is seems especially important to consider given Erik's stark contrasts between school science and his contemporary scientific practices experience and his reflection comment, "I'm not looking forward to going back to regular class."

The next two case vignettes support the themes of processes related to practice-linked identity seen in this case study of Erik. Mainly, engagement in contemporary scientific practices can shift ideas about the scientific enterprise and learners' relationships with scientific practices

and that making disciplinary experts' work visible allows for students to make powerful connections between their work and that of the experts.

**Case Vignette: Julie – Becoming cognizant of interdisciplinary science.** In this case vignette, Julie, a student at Innovation High School, participated in the first enactment of the infectious disease unit. This vignette is important because it supports and extends the theme in the Erik's case study that student engagement in the epistemic practices of contemporary science, as students interact with disciplinary experts, can help them debunk the perceived boundaries between disciplines and highlight that confirmatory labs are not representative of scientific work and discovery—which they often experience in school science. Learning environments focused on contemporary project-based instruction make this possible by being spaces where material and relational identity resources provide opportunities for students to then voice their perspective about their place in the set of practices under study — by surfacing ideational identity resources. Julie talked about her interests in mathematics and computer science consistently throughout the unit. She was on the First robotics team at the high school and used her involvement with the team to develop her computer programming skills. She reported that her mother, a biologist, often talked with her about pursuing a career in the biological sciences. Julie did not see the connection between biology and her interests in computer science and mathematics until she began to work on the curriculum project which involved computational modeling of infectious disease spread across the globe (Bajardi et al., 2011). Through iterative development and tweaking of her team's epidemic models, she worked to identify the underlying mathematical expressions that drive the software-generated simulations. Her daily project work always focused on understanding how her team's research about the effects of airline travel on disease spread could be explained mathematically. She guided her team in comparing their infection curves

generated from the modeling work with published data from research at the Centers for Disease Control she found online. Near the end of the unit, a disciplinary expert collaborator who helped to design the unit, came into the classroom. He talked about his educational background, interests, and current work and students gave elevator speeches about their work to him. His experience included a unique interdisciplinary blend of computer science and infectious disease expertise that led him to be hired in this current position. This is becoming more common as scientific inquiry is becoming increasingly computational. After interacting with a computer scientist who routinely uses computational models to study infectious disease scenarios, Julie told the researchers about how her mom has always pushed her toward biology but she did not see the connection between biology and her interests in computer programming until she participated in this unit.

Through deep engagement with technological tools, Julie's practice-linked identity development was driven by her interests and resourced by the curriculum, educators, and disciplinary experts in ways that allowed her to access knowledge about extended learning pathways that lead into careers at the intersection of biology and computer science. This overlap of (inter)disciplinary practices and the supporting material and relational identity resources with ideational resources allowed Julie's identities to become visible in the learning environment (Markus & Nurius, 1986). Her participation reconciled tensions between expressed future selves and allowed her to see herself as a possible interdisciplinary expert in biology and computer science.

**Case Vignette: “At the forefront of the research field.”** This second vignette, focused on the same unit and iteration of Julie's participation, is important because it echoes the theme from Erik's case study that relationships with others in the learning context —relational identity

resources — allow students to compare and value their work within the context of the contemporary scientific work which then leads them to express ideational identity resources about how their work is valued in the learning environment or the larger scientific context. During the Spring 2011 unit enactment, a team from Innovation High School wanted to study the effects of poverty on the spread of infectious disease but the software’s design did not offer a straightforward way to accomplish this. Instead, the team decided to alter parameters in the model to simulate poverty. One strategy they employed was to decrease vaccine efficacy and vaccination rates. When they had a Skype session with experts, they shared this work with the principal investigator and designer of the modeling software, and he told the team that this was an excellent choice of study design given the limitations of the system. He also let them know that his team is addressing this limitation and is working on building this capability into the software. During his final review of their research he commented, “The inclusion of economic and health infrastructure indicators in large-scale simulations is an interesting direction at the forefront in the research field.” The technology platform allows students to connect with disciplinary experts and resources as they deepen their participation in contemporary scientific practices while working on problems related to those of the contemporary scientific field. During the unit, after a real-time interaction with a modeling expert, a student in this group noted, “[the scientific modeler] does what we do.” This statement is similar to the one Erik made about doing the same job as scientists and it can be understood as an ideational identity resource to view one’s place in the scientific practices as on par with the work of experts in the field.

### **Synthesis of Salient Qualities of the Learning Environment**

There are several aspects of the contemporary scientific practice-focused learning environment that support access to and opportunities for uptake of practice-linked identities — a connection

between self and the activity (Nasir and Hand, 2008). Three categories of setting aspects were analyzed with respect to the case set, drawing from Nasir and Hand (2008): access to domain, access to roles and accountability, consequential production within the environment. I explore themes across the cases in each category.

*Access to the domain.* The value in designing learning environment by starting with issues, tools, and techniques that are part of the cutting edge work going on in the field is that these then become part of the learning experience for students and they open up space for seeing science as something different than what usually happens in schools. Erik, Julie, and the team studying poverty and disease spread all experienced access to the contemporary domain knowledge and practices through their project work and also through their interactions with disciplinary experts. As novices pursuing interest-driven projects, they were able to access aspects of the domains normally reserved for practicing scientists such as the interdisciplinary nature of biology and the tools and techniques specific to each project. This allowed students to come together in real project work—an aspect of domain access found to be crucial in identity shifts related to the scientific practices of the domain. As Heath (2012) writes, “just as diverse levels and kinds of knowledge and skills create groups of experts scientists, so group projects that deeply engage novices must include a range of expertise and interests and ideally access to ‘real’ experts or models” (p. 257). Informal learning environments more routinely feature such qualities in the project-related learning environments (Heath, 2012; NRC, 2011), but this analysis importantly shows that such work can take place within the constraints and affordances of formal schooling, adding to the research base on project-based instruction (Darling-Hammond, et al., 2008).

*Roles and accountability.* Accountability to carry out specific roles in a setting highlights

the expectation that students will engage with and become competent in practices associated with the domain (Nasir & Hand, 2008). In the case studies presented, students were positioned or assumed positions where they could learn new practices and often meaningfully engage in epistemic work. They viewed their roles as central to the project work and as part of the processes of understanding and seeing themselves within the domain. In the Erik case study, not all students took on the central pipettor role and David's participation in the group could be viewed as not necessarily having the same level of accountability. This raises a pedagogical issue that even within well-designed learned environments, it is difficult to have equal engagement across all roles for all students given constraints in materials and time and necessary divisions of labor. That said, David used available 'flex time' in the project work to develop some competency in the material practice as he desired.

*Consequential production.* The third aspect deals with the "opportunities to make a unique contribution and feel valued" (Nasir & Hand, 2008, p. 148). In the context of contemporary scientific work, this means producing work that is consequential to the students' in relation to knowledge that is important for the domain, the community, the individual or all three. As we saw in the global transmission of disease and poverty student, the expert recognized the students' work as being consequential and at the forefront of the field. In work presented in Chapter 3, I found that students saw their project work as relevant to the outside world, often addressing issues of broad human concern. They also often viewed their work as being parallel to the prestige scientific work being done by professionals, which heightened the potential for unique contributions from their work

These cases have shown that engaging youth in contemporary scientific practices led to processes that promoted their development of scientific practice-linked identities. But how can

practice-linked identity be supported when students bring their expertise and identities into the work? Is there more to be gained by coordinating contemporary science with the out-of-school interests, knowledge and practices of youth? Next, I explore a set of cases related to the impact of recognizing and supporting the use of existing identities on the development of practice-linked identity.

**Case Study: Anthony — “I prefer to spend my free time playing video games”**

The issue at stake in this case study is understanding the ways in which the existing identities of learners come into play and can sometimes be intentionally leveraged during engagement in scientific practices to support or hinder development of scientific practice-linked identities. Leveraging learners’ expertise and building on prior interests and identity was an intentional design principle of the instructional model. Students have multiple identities available to them because “one inhabits multiple worlds and is involved in diverse communities ... any given individual has a repertoire of identities when seeking membership in a new community of practice” (Tan & Calabrese Barton, 2008, p. 49). This case is an instance of Anthony leveraging practices related to an existing identity to become recognized as an expert practitioner in a new scientific practice-linked identity. Anthony was a sophomore at Innovation High School and had a deep interest in computer gaming and software engineering. He was in Mrs. White’s biology course.

In the first iteration of the genetics unit, Mrs. White and the research team implemented a shortened unit that included a week of Foldit game play culminating in the four biology classes competing against each other for the highest average class score on a protein folding puzzle related to stem cells. Students began to understand how to play Foldit through a series of tutorials supported by a short exercise that asked them to note parts of a protein (e.g., backbone,

side chains), types of interactions in a protein (e.g., hydrogen bonding, hydrophobic/hydrophilic sidechains), and the purpose of tools available in the game (e.g., wiggle, shake, transform). After they had sufficient time to work through most of the training tutorials of the game, two to three class periods, we introduced the contest puzzle using a quick presentation that described the molecular biologists' interest in solving this protein structure and how it could be integral to reprogramming stem cells. The contest puzzle was a protein called nanog, a core pluripotent factor involved in reprogramming stem cells. It had already run as a puzzle available to the larger community of Foldit players without much success. When I talked with the physician and scientist who submitted the puzzle, he noted that it was a medium-sized protein, its sequence did not suggest evolutionary importance and pieces of it seemed to be highly variable. Despite possible importance for inducing cells to become stem cells, in this case, Foldit was unable to help solve the protein folding structure of nanog. From an educational perspective, it was an interesting and relevant protein to connect to a bigger picture for students but it was not the most groundbreaking from the science perspective. In future iterations of the curriculum, a smaller protein that had been deemed more Foldit-friendly was used for the contest. It is important to note this case study represents the first time we had tried to implement Foldit tutorials and a contest into the classroom and therefore, the researchers and teacher were still learning the complexities and upper level options within the game.

On the second day of the contest a day was devoted to contest play as well as housekeeping items in the classroom. Mrs. White was checking students' notebooks for completeness and grading purposes. We learned that Anthony had continued playing the context protein at home from the previous day and discovered aspects of the game we did not know existed. This is an instance of a compulsory learning experience leading to a volitional follow-on

engagement. In retrospect, this was not surprising. On his online profile that he crafted at the beginning of the unit, he wrote, “I prefer to spend my free time playing computer games.” He also noted that he wanted to become a computer engineer after college, and, therefore, his favorite area of study at the time was computer hardware engineering. On their profiles, we asked students to comment on one thing they were interested to learn about genetics and Anthony wrote that he wanted to learning “how the ‘coding’ works in DNA.” From his profile alone there are clear connections between one of his areas of expertise — gaming — and one of his interests — how genes act as a code. Foldit’s premise builds upon the basic idea that DNA codes for proteins and that proteins have specific folded structures that allow them to do function appropriately. A better understanding of protein folding can help to solve problems in the biomedical sciences.

He came into the classroom on this day during the Foldit contest with significant expertise after playing the game at home, completing the tutorial levels, digging into the website, learning about tools from the larger community of Foldit players and downloading a science journal article about the use of recipes for protein folding within the game (Khatib, et al., 2011). He brought in his personal computer so he could make sure the Foldit play continued seamless from home to school, having arranged it to work with the recipe programs as he wished. He had it open on his desk. In addition, all his notebook papers were spread across his desk and he was organizing them at the last minute, in class, before the teacher called him up to check its contents. His computer sat pushed to the back with the screen turned off to hide its activity — likely to keep the recipes he was using a secret or because this was his common practice when he left a program running while doing another task —, and he checked it periodically while organizing his notebook and talking with the three other students at his desk. Two episodes

epitomize his activity on this day and how he was able to draw on his expertise and subsequent positioning in the classroom to become known as “the Foldit expert.”

**Episode 1: How do you know what to do?** In this episode, Anthony was organizing his notebook, Andrew was sitting next to him working on the Foldit contest puzzle and Patty and Cassie sat opposite also working on the puzzle. Patty started the conversation by asking Anthony about how he knew so much about Foldit.

1 Patty: Hey Anthony, how do you know what to do?

2 Anthony: How do I know what to do? I read science papers (laughs) that's literally what I did to get to this point. I had...I read a well not completely but I read a science paper.

3 Andrew: I really hate how a you know when you try to add recipes and like oh no you can't do that (inaudible). Have you ever got that?

4 Anthony: Wait, what?

5 Andrew: When you like, ok you got a recipe

6 Anthony: That Foldit thing doesn't open

7 Andrew: Yeah

8 Anthony: Yeah, I've never gotten that

9 Andrew: Alright [shakes head, switches window on his computer]

In line 1, Patty positioned Anthony as having relevant expertise to the task at hand. Around this time, we (two researchers and the teacher) also realized Anthony had a great level of expertise and more knowledge about the game than any of us. Anthony responded to Patty in line 2 laughing but confident that he read a science paper to develop expertise. Anthony's response is a relational identity resource as he talks about his expertise development strategy and accepts

Patty's question that positions him as an expert, This begins to describe the possible ideational resources in play as he began to explore the relationship between his existing gaming expertise and his place in these new scientific and gaming practices. Episode 2 explores how he found and leveraged this scientific paper. In line 3, Andrew made a self-positioning move as someone who is also in the know about the community of resources. Andrew was also an expert gamer and him and Anthony spent much conversation time analyzing the functionality of the game such as the exchange in lines 3 to 9. As the conversation continued, Patty asked Anthony about how to use a tool called the Wiggle tool. The Wiggle tool circulates through possible confirmations of the protein to try to find the most stable configuration for pieces of the protein.

10 Patty: So this wiggle, how do you...

11 Anthony: Wait til it gets to sorta steady point, til it stops getting points. It can be really tedious

12 Patty: So how do you get the bottom one to move? Where (inaudible)

13 Anthony: Um you have to create... You have to get rid of all the clashes all the voids and you can't have of any of the exposed, it sucks, but you have to make the space, make it as small as possible without creating any clashes of side things.

14 Andrew: And that is the master talking.

15 Anthony: Not really, I'm only, I'm only number one in the contest.

16 Anthony: (long sigh), where is it? Here it is. [referring to work he is putting into his notebook].

17 Patty: So just leave it to to wiggle? That's all?

18 Anthony: (walks over to view Patty's screen) Well once it gets, once the point thing is kinda stable. (4 sec.) umm. (inaudible, points to screen). What I'd do is I would look around and then it shows where or you could um, you could make some rubber bands from there to there and use this recipe to bend this and get this on top of it.

At the end of this part of the exchange, Anthony was called off screen presumably to another table to help another student. Others at the table continue working quietly with intermittent conversation related to the game. In line 10, Patty asked a question about a specific tool — the wiggle tool — and Anthony responded with the first of many instructional moments where he shares his expertise in social arrangements across the classroom. He used his experience with the tool “it can be tedious” to emphasize that success requires some patience. In lines 12 and 13, Patty asked a follow up question which we cannot completely hear and Anthony used his specialized game vocabulary to describe how the puzzle has to be manipulated — fill the voids (empty spaces) but avoid clashes (interactions between similarly charged sidechains in close proximity). Andrew — in line 14 — then made a strong positioning move in response to Anthony's line 13 utterance calling Anthony the master, to which Anthony responded that he is only really the master of this contest not all of Foldit. In line 16, Anthony was clearly still multitasking and working on his notebook, but in line 18 he moved to the other side of the table to help Patty and continue the instructor/expert role. In this line, he was helping Patty move from novice play (e.g., just using the tools visibility available on the screen) to more expert play by approximating what he would do and introducing her to a recipe. Recipes are not intuitive or made clear to new users. Anthony's familiarity with recipes as material resources within the gaming environment also acts as a material resource in the learning environment where Anthony

uses recipes as entry into an expert role within the classroom, which gives him opportunities to take up the practice-linked identity related to gaming for scientific purposes.

In this next excerpt, the students talked about the functioning of tools in the game and how to use them quickly and effectively.

23 Andrew: Anthony, I really hate the tweak tool. Its like its

24 Anthony: It doesn't work for you, jeez.

25 Patty: How do you put bands?

26 Anthony: Um, Shift, Click, and Drag

27 Anthony: (Checks his computer screen.) Oh oh ok I really gotta pay attention to the chat feed more often (walks away - likely to respond to a request from the chat.)

When Anthony returned in line 23, he and Andrew continued banter about play strategy and what worked for them individually — some of this can be attributed to game glitches that affected some players but not all — and in line 25 he answered Patty's question about tool usage with a short-cut, "Shift-Click-Drag," that he knew without looking at her screen. He then woke up his computer, checked his protein, and scrolled through chat where he noticed that his classmates had been asking him for help on chat. He says, "I gotta pay attention to chat more often" in this move he signals his sense of obligation that he is responsible for others in the room. This obligation built over time and Anthony continued to take on the classroom responsibility. The research team pulled the chat data later and saw Anthony advertise his willingness to help and students from across the class requesting his assistance on their puzzles from troubleshooting to overall help improving their score, for example:

<+Anthony1> If anyone needs helps. Message me. Or come and get me.

<+Britt2121> hey anthony. come here

<+Kevin32> Anthony

<+Kevin32> SHOW ME YOUR WAYS

<+Gina6> ANTHONY!!!!

<+Gina6> WHERE ARE YOU?

<Gina6> I CANT SEE MY PROTEIN

Through chat and follow-up Facebook posts that we overhear students talking about, Anthony becomes positioned as the “go-to expert” by students and educators in his classroom and to some extent in the other class periods as well via social media and educators making recommendations we learned from him. The episodes accumulate to show the building demand on Anthony’s time and expertise in the classroom and they reaffirm his place in the practice in a way that promotes collective value in the setting. This building sense of obligation is an ideational resource for Anthony that created demand and value on his expertise related to the practices in play in the classroom.

**Episode 2: It’s the PNAS 2011 paper.** This episode came about during an interaction with Anthony around the resources he had employed to gain expertise. I was specifically interested in learning more about recipes and their use in the game. When we shared a summary of this episode with a member of the Foldit development team, he was nervous that Anthony would be able to beat everyone if he used the most successful recipe.

28 KVH:       What are you reading to figure this out?

29 Anthony:   This is actually I found online. It’s the PNAS 2011 paper

30 KVH:       It’s called Algorithms...

31 Anthony:   I’m not sure what it’s called

32 KVH: and what part of that has helped you?

33 Anthony: Um they talk about the recipe using habits of the top Foldit players.

In this exchange, I asked Anthony how he figured out how to use recipes. We were talking next to his computer and he pulled the paper up on the screen. He found the paper on the Foldit website where they linked to multiple scientific papers they have published in highly regarded scientific journals. The Foldit website contains many resources for playing the game including blog posts, community forums, and a set of recipes. We did not know anything about recipes until Anthony told us about them. The access of recipes required Anthony to understand something about gaming culture that non-gamers do not anticipate, that is, the existence of an online support community. Anthony's gamer identity allowed him to locate and access the expertise of the Foldit player community. He navigated the "affinity space" (Gee, 2004) of Foldit to access and interact with other more expert Foldit players, use tools and algorithms developed and shared by players, and find a scientific paper that he read and used to guide his Foldit game play. An "affinity space" is a location where knowledge is shared across all levels of members. For Gee (2004), in these spaces Learners 'apprentice' themselves to a group of people who share a certain set of practices (e.g. learning to cook in a family, learning to play video games with a guild, learning to assemble circuit boards in a workplace, learning to splice genes in a biology lab), pick up these practices through joint action with more advanced peers, and advance their abilities to engage and work with others in carrying out such practices" (p. 70). Anthony has experience with gaming affinity spaces and was familiar with the research practice used in the gaming community that involves gamers sharing knowledge, tips, and tricks about a game. It is exceptional and powerful to have students extend their learning to out-of-school time using a

practice they are already familiar with—and it is contingent upon having a “affinity space” resource collection available online, a particular historical fixture of this learning arrangement.

34 KVH:       Awesome... so have you been finding their recipes by using that or...

35 Anthony:   I've been using some of the recipes that they've been using and using them at certain times in the game to get maximum points out...out of the puzzles.

36 KVH:       So its not just the recipes you are using but also

37 Anthony:   It's when you use them

38 KVH:       It's when you use them

39 Anthony:   Yeah

In line 34, I continued the conversation by asking him about how he accesses these resources and then how he decides which ones to use. In the subsequent lines, Anthony and I are having a genuine dialogue where I am learning something new, which is in contrast to opportunities he might have to interact with educators in a traditional classroom. This gave me additional information to purposely position Anthony as an expert with relevant knowledge to share and add to the learning environment. The relational identity resource at play in this episode is Anthony's connection to the educators in the setting who leverage his expertise and promote the expectation that he will teach others what he knows about the game through his research. Excited about the prospect of the chat tool within Foldit being useful in a classroom setting as a way to share expertise, we told students that they can use the chat tool to ask questions of their classmates, which was especially important because they were competing against other classes.

The paper helped him make decisions about what recipes to use and how to use them. There are hundreds of recipes listed so for a new player, this use of the paper as a way to figure

out how to access useable resources is an effective and important strategy. In the next section of transcript, I continued to ask him about recipe strategy.

40 KVH: and is it general across different puzzles or ..

41 Anthony: It depends on what kind of puzzle I mean some you have to change the chemical structure, other ones you have to change physical structure so its all dependent

42 KVH: so this one we are playing is change the physical structure?

43 Anthony: Yeah

44 KVH: So that then dictates the order in which you should do recipes?

45 Anthony: Um not so much but the kind of recipes. Because I have ones that will mutate them and I don't I can't use them right now because you can't mutate. Other ones that shake it around and get it done. I have to go. I have to go help.

46 KVH: Sorry, go help.

Anthony clearly had a nuanced understanding of the usability of recipes, he noted that it matters both when and in what order you use recipes and also that the recipes you choose can actually function on the particular puzzle. In line 45, he explained that in this particular challenge puzzle you are not allowed to change the amino acids in the protein so choosing a recipe designed to cycle through mutations to increase score will not work in this case. Anthony ended the exchange because he realized that someone in the class needed help, continuing his obligation of classroom responsibility and his educator-sponsored role for helping his classmates. By the end of this short episode, through social positioning from other students, educators, and himself, Anthony takes on the practice-linked identity of science-related gaming expert, which grew from

his existing gaming expertise. In addition, Anthony reported that he learned about key ideas related to proteins and their structure in the process, he wrote, “Using Foldit I learned about hydrophobics and hydrophillics, something I did not know before I started using Foldit.” The gaming integrated into the learning setting gave him specifically an opportunity to feel valued in the classroom and in the greater Foldit community. Next, I present a contrasting case vignette of shifting participation from reluctant to fully engaged due to a small shift in the learning environment context.

**Case Vignette: Lily — “Shifting Foldit Participation in Competition.”** The rationale for this vignette is to demonstrate how small changes in learning environments and links to students’ interests can dramatically change their participation. This case vignette takes a different perspective on the interactions between practices in learning environments that lead to practice-linked interest and identity shifts in short timescales. We piloted two different curriculum units at Innovation High School. The first, *Predicting and Preventing Infectious Disease* was piloted in health classes and the genetics unit was piloted in biology. Across these two courses, some students experienced both units. Both units had games for learning embedded in the curricular arc. Lily was one of the students in both classes. When we met her in her health class — an elective course at the school that teachers did not usually enjoy teaching — she participated in the class but often expressed her concern that by doing projects or playing games she was missing content that she should learn in health class. She had a traditional school stance of many strong students of being there to learn specific ideas. This was an interesting stance, given her school was a STEM magnet school focused on aerospace learning and careers and worked to promote a project-based learning approach across its courses, which was a branded approach within the school and part of its larger community communication strategy. Lily also reported

being interested in pursuing a career in engineering, possibly aeronautical engineering. The students often did projects and presented those projects to local industry professionals. However, at that time, almost all of the projects that students participated in were directly related to the aerospace theme and doing projects not related to the theme was discouraged. When we started the Foldit tutorials in the classroom, Lily expressed her hatred of Foldit and participated resentfully and was affectively upset about having to play another game in this unit. This engagement affect continued until we began the Foldit contest protein that was related to reprogramming stem cells. This was the first time we had discussed stem cells in class. Lily, however, became excited about the contest; she had a high level of engagement and was tracking and talking about her score and place in the contest. In the periods after hers, her friends came in talking about the strategies Lily recommended to them. Not only was she excited in the class but she was also talking about it after class and trying to help her friends.

As researchers, we were intrigued by her change in stance and demeanor from resistance and dislike to full engagement. I looked at her student work captured online (e.g., responses to prompts and online profile) to hypothesize as to why she made this switch in participation. First, Lily reported she learned about energy and its role in protein folding from playing the game but that she had open questions about the game in a forum post reflecting on the game. She wrote, “One thing I learned about protein folding is that proteins want to fold in the way that uses the least amount of energy. How do the ways of folding a protein on the computer apply to folding a real protein? Why don't proteins always fold the way that takes the least energy, and if they do, then why are they sometimes folded wrong?” She learned a key aspect of the game and was still interested in a deeper understanding of how the game related to actual protein folding. In addition, in her profile under “What are you an expert in?” she noted that she does gymnastics,

presumably competitively although we did not hear her talking about gymnastic competition in class, she did comment on her place in the contest especially when she went up or down in the standings. In addition to the competitive aspect of Foldit that could have induced her engagement, when asked what she was most interested in learning about genetics, Lily wrote, “I’m interested in learning more about stem cells because I don’t know a lot about them and I am curious to find out more about them.” The other partial explanation available from the data is that Lily shifted in her engagement because the puzzle was related to a scientific interest of hers. Although I cannot definitively pinpoint the exact explanation, the benefit of building instructional strategies and tools that make students’ interests and expertise visible to teachers for immediate use in instruction is that building directly on students’ interests can shift students participation in ways that then allow them to shift their positioning and recognition in the classroom. As Lily engaged in the contest, she became positioned by her friends as someone with relevant expertise and her standing within the contest helped contribute to her class’s victory in the contest because of her consistently high score and sharing of play strategies. The material resources of the game within a certain instructional context, could have caused Lily to shift her participation and thus she could have shifted her practice-linked interest related to the value of games in relation to science. In addition, with this shift, her relationships with her peers in the context also shifted — her score was visible to everyone near the top of the leaderboard and her friends leaned on her for strategies and ideas of how to play. Both of these things gave her social recognition in the classroom and associated relational resources that either supported or resulted from her practice-linked shift in interest.

## **Synthesis of Salient Qualities of the Learning Environment**

Participation in a learning setting should extend beyond learning to actually supporting the development of who one is (Nasir & Hand, 2008; NRC, 2009). These case studies demonstrate the affordances of the learning environment — particularly the use of citizen science gaming — for connecting to existing identities and supporting practice-linked identity development. By integrating gaming with a competitive aspect into the learning environment along with space and expectation for collaboration across students in the class, the formal schooling environment provided Anthony and Lily with all three aspects of an environment that Nasir & Hand (2008) found to support practice-linked identity.

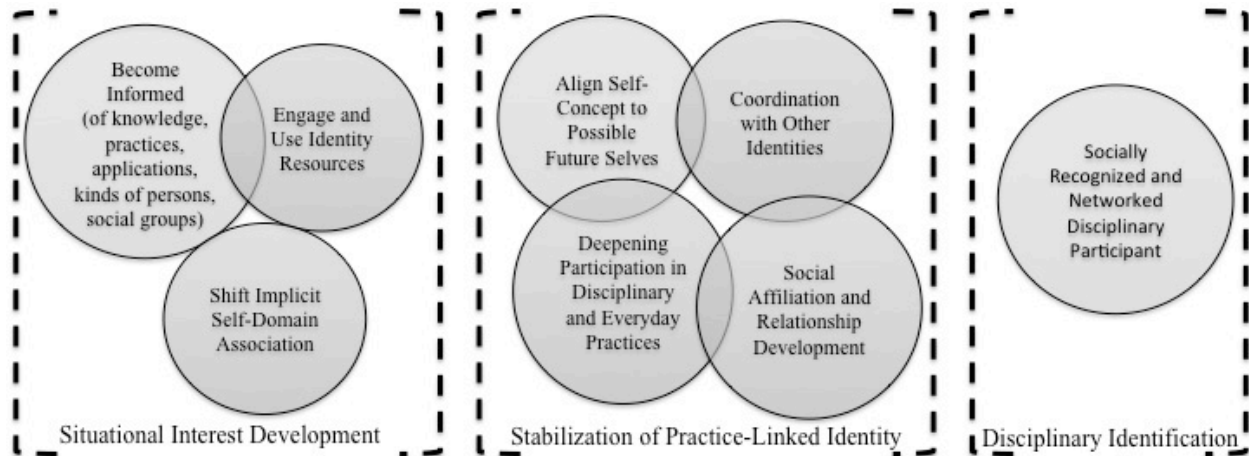
*Access to the domain.* Through playing Foldit, students were able to access a community of people gathered around a common problem. Foldit is successful at helping to solve protein folding problems because humans are slightly better than computers at configuring proteins. By integrating Foldit into the classroom and creating a competition around a puzzle clearly linked to genetics and cell biology, students were able to access the domain of protein modeling not usually accessible to novice learners. In addition, Anthony's case study showed how he was able to use leverage his access into the gamer community around Foldit to develop expertise he then shared with his classmates.

*Roles and accountability.* The competition aspect of this particular learning environment — where the four classes of students were competing against each other on the contest protein — increased the level of accountability in the classroom and led to peer expectations of full participation. In Lily's case, she was accountable to her peers for helping to provide strategies she had gained from her new found practice-linked interest in the game. In Anthony's case, the accountability arose from this positioning as “Foldit expert” in the classroom and as someone

who was constantly available to help struggling peers. The integration of game-based learning scientific practices into the classroom allowed for aspects of peer-influenced accountability. *Consequential production.* By playing the Foldit contest protein, students were working on a puzzle submitted by the University of Iowa Carver School of Medicine to identify possible protein configurations for a transcription factor related to inducing pluripotency in stem cells. It turned out that the protein had many issues and was not suitable for solving through the game. This is a general affordance of citizen science efforts for increasing space for students to make a contribution to the efforts that go beyond what is usually deemed possible in traditional science classes. To move beyond the structure of learning settings, these cases also demonstrates how learning settings can provide resources for integration of existing identities for positive moves across a practice-linked identity development trajectory.

### **Discussion**

Although researchers have identified the ways in which the development of practice-linked identities can be supported in learning environments—typically informal ones—little is known about the processes that support identity development over time in specific contexts and the intermediate steps that move learners along trajectories towards socially recognized and networked disciplinary participants. For Nasir & Cooks (2008), practice-linked identities reflect, “both the contours of a practice and the particular ways in which an individual integrates these into the person he or she is becoming” (p. 175). This study looked at the ways in which learners integrated aspects of the practices into their possible future selves. Figure 3 depicts the theoretical model introduced earlier on that begins to describe the pieces of identity development in play as practice-linked interests and identities stabilized over time.



*Figure 3.* Stabilization model with three phases of practice-linked identification (Bell, in preparation).

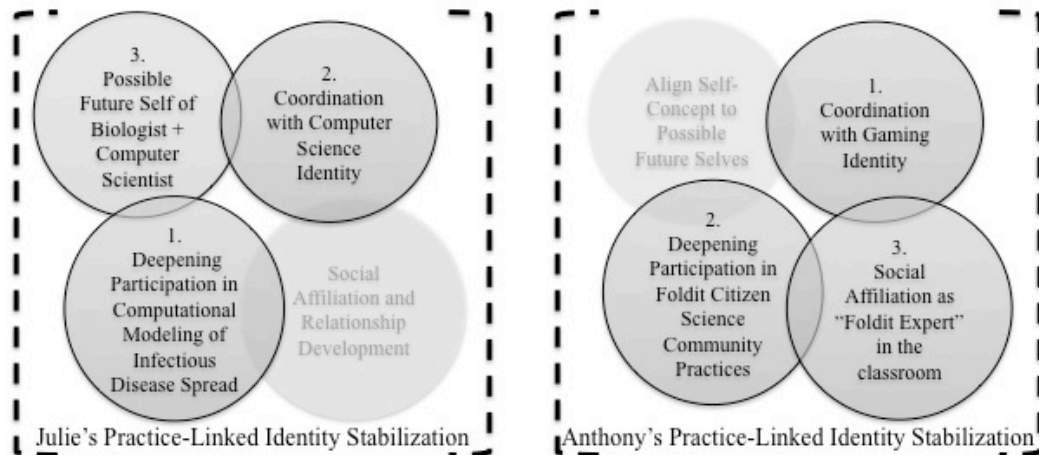
A key aspect of situational interest development is the ‘kinds of persons’ associated with the domain that learners might have not been previously aware of (e.g., as clearly highlighted in the Erik and Julie cases). Learning about persons and the kinds of disciplinary scientific work they do has significant potential to make students aware of themselves in relation to those activities in which those kinds of persons participate. From a linguistic anthropology perspective (Wortham, 2009), the references to ‘kinds of persons’ in situated talk becomes a token that gets attached to a person or that allows the person to reference and learn about a social practice that is unfamiliar to them. It then becomes a way for them to potentially renegotiate their understanding of two (or more) social practices that are in tension (e.g., school science vs. professional science). In this study, Erik came to understand the kinds of persons who pursue real scientific work are in tension with the type of scientific work that is standard in school science.

In the next phase — stabilization of practice-linked identity — both Erik and Julie, through deepening their participation in the scientific practices of their investigations —DNA barcoding and modeling of infectious disease transmission, respectively—found alignment between the biological sciences and their future possible selves. This was also influenced by

their interactions with disciplinary experts that gave them experience with the type of work that happens in the domains, learning about the kinds of persons who do that work, and being able to engage in corresponding versions of that more professional and contemporary work. It was also supported by productively coordinating this work with previous interests and identities they each held.

Finally, this study demonstrated the project work of the curriculum allowed for significant progress for these learners in the first phase and second phases of identification with a promise of increasing full recognition for many of them. Elsewhere — in informal learning environments — this had been documented (Bricker & Bell, 2014; Bricker & Bell, 2012; Stromholt & Bell, in preparation; Zimmerman, 2012), but further research is needed to document states of full recognition and corresponding support within formal learning settings.

**Extending details of the stabilization model.** The cases described in this study add to the model by describing features of practice-linked identity stabilization that involve nuanced kinds of interactions that happen within and between the model's components. Two additions to the model are important for mapping practice-linked identity stabilization over time. First, *deepening participation and coordination with other identities are linked phenomena*. This linkage is bi-directional and the cases of Julie and Anthony demonstrate two different ways in which coordination with other identities and deepening participation in disciplinary and everyday practices interact to stabilize practice-linked identities. Figure 4 compares the nuances at play in the two cases within the center stabilization section of the model.



*Figure 4.* Comparison of the detailed identity stabilization processes for Julie and Anthony.

For Julie, deepening participation in computational modeling practices to address a problem in contemporary biology — the transmission of infectious disease via human travel — led her to reassess a perceived tension between two fields — biology and computer science — which allowed her to coordinate her computer science identity with her mother’s interest in biology in a way that opened space for her to consider a possible future in an interdisciplinary field that combined these two interests. In this case, the directional linkage from deepening participation to coordination with other identities led to her alignment of possible future selves. For Anthony, his recognition of the coordination between his gaming identity and the Foldit citizen science protein folding gaming practices in the classroom was instrumental in his deepening participation in the gaming and scientific practices which led to a social recognition as the “Foldit expert” in the classroom. The coordination between Anthony’s outside of school expertise was facilitated by the game-focused instructional component of the curriculum that made it both safe and valuable to bring this expertise into the classroom. Between interest development and a fully stabilized practice-linked identity, there are specific ways in which identities can begin to be stabilized over time.

This leads to the second point, that these entry points into the stabilization model can be characterized by the arrangements of resources and qualities of the learning environment. Second, *material, relational, and ideational identity resources and qualities of the learning environment mediate multiple entry points into the practice-linked identity stabilization model.* Nasir and colleagues (Nasir & Hand, 2008; Nasir & Cooks, 2009) have a line of research interrogating the static and interactional characteristics of learning environments and interactions that support youth in seeing a set of practices integral to one’s self — a practice-linked identity. Their kinds of identity resources and features of settings associated with the science investigation in this study are valuable for understanding how youth enter into identity stabilization processes. In each case presented in this study, entry points into this stabilization model varied by the ways in which practice-linked identities were available for uptake by the focal students, as shown in Figure 5.

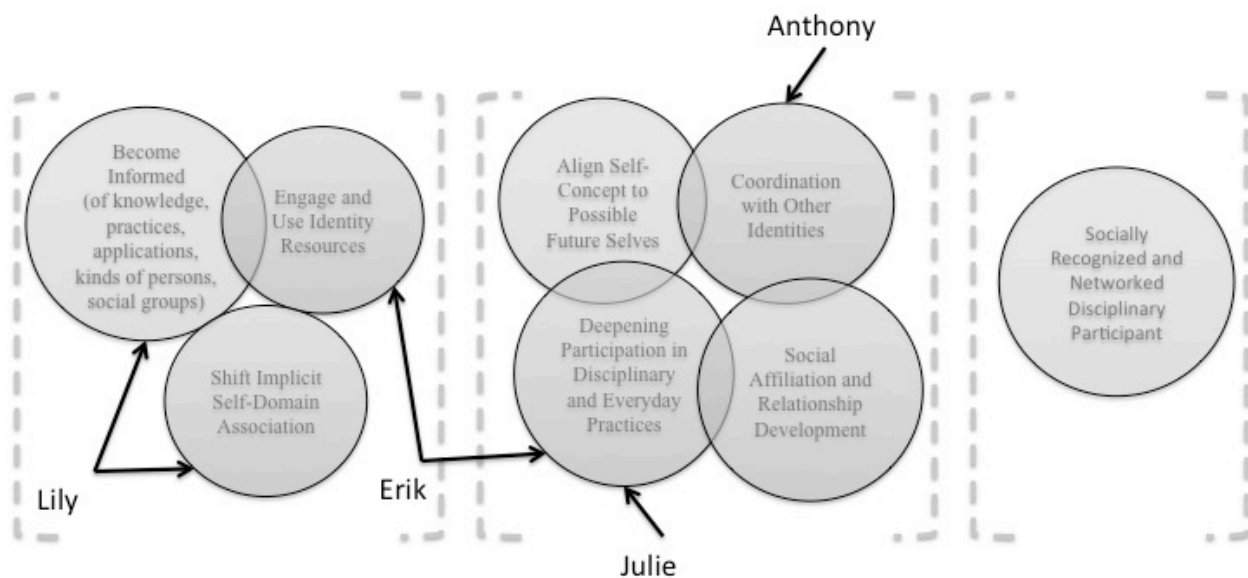


Figure 5. Entry points into the stabilization model.

Characteristics of learning setting set up the possible arrangements of identity resources that can become available for students in the learning environment and therefore the combination

leads to facilitation of various entry points into the model. Julie and Anthony's entry experiences are described in the linkage between deepening participation and coordination with other identities. The identity resources in play for Julie were mainly ideational — belonging to computer science — and relational — relationship with her mom who worked in a biological sciences field. Anthony's identity resources were primarily material through his access to online resources. Similarly, Erik was brought into the sociomaterial practices of contemporary science through the DNA barcoding project where he had newfound access to material resources (e.g., scientific tools) that gave him access to the scientific domain in a way he had not experienced before and this led to an ideational resource through changing his understanding “what science is.” On the other hand, it is also interesting to note the case where Lily was disengaged throughout much of the work and something about new information available to her through the Foldit contest puzzle shifted her self-domain association, likely at an implicit level that then became explicit, and brought her along the identity stabilization process. Entry points are meant as a way to trace the interaction of setting features and identity resources in way that facilitates the stabilization of identities. But as we saw in the varying interactions between deepening participation and coordinating with other identities, there will be nuances in this process across time as learners encounter different arrangements associated with the sociomaterial scientific and everyday practices as it relates to their histories, interests, and goals.

Learning environments that are powerful for supporting the stabilization of learners' practice-linked identities in science can be designed and implemented in formal school settings. Through the focus on contemporary scientific practices, the curricular interventions helped create classroom learning environments—rich with material resources and experiences that included relational and ideational identity resources—that provided youth with multiple entry points for

stabilizing practice-linked identities related to science. Science in school is often solely focused on learning content, but that that goal can be attended to while also helping students participate in becoming scientists as well. As a community, we need to wrestle with the trade-off represented in these two approaches—and explore which will help youth have increased degrees of freedom to pursue life goals, especially youth who often encounter learning environments that do not provide them with these high status identity-related learning experiences.

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## Chapter 5: Contemporary Scientific Practice-Based Approach to Learning and Teaching: Conclusions, Implications, and Future Research

Together, the three analytical chapters in this dissertation investigated the implementation issues and the educational opportunities associated with “taking the practice turn” in science education. This pedagogical shift focuses instructional experiences on engaging students in the epistemic practices of science both to learn the core ideas of the disciplines, as well as to gain an understanding of and personal connection to the scientific enterprise (NRC, 2012). In this set of concluding remarks, I look across the three studies to synthesize the conclusions and implications that can be drawn across this body of work. While each study includes a tailored theoretical framework, all studies are grounded in the social practice theory definition of practices drawn from the philosophical frame from Rouse (2007) that accounts for tracing the goals of scientific practices, the contexts of the performers, and the interaction of specific practices with others. I leveraged the theoretical frame of Dreier (2009) to conceptualize learning along cultural pathways (Bell, Tzou, Bricker, & Baines, 2012) in order to investigate how learners and teachers encounter—and often attempt to coordinate—multiple structures of social practice that shape situated performances of the scientific practices.

In Chapter 2, I examined the teacher-researcher collaboration that supported the implementation of the year-long biology curriculum across two regions in the country. This design-based implementation research study (Penuel, Fishman, Cheng, & Sabelli, 2011) explored the dilemmas that arose when teachers implemented a new intervention. The chapter described how the dilemmas arose and were managed through a co-design collaboration between teachers and researchers. Unique challenges and affordances arose in each setting as the curriculum was implemented in each local context. The teacher-researcher collaboration created a space for

sharing instructional practices across teachers and researchers from very different backgrounds and locations, which allowed for meaningful dialogue and opportunities for professional learning.

In the design-based research of Chapter 3, students' engagement in contemporary scientific practices was shown to be variable across student groups and to be facilitated by interest-driven learning strategies used to frame project engagements. Student performances of the epistemic practices are instantiated in the contexts of performers who are pursuing a common goal and encounter interaction between practices across the four bundles of social practices at play: scientific practices, school practices, youth/everyday practices, and relevant social domain practices. We saw how students' engagement in epistemic practices in contemporary science investigations supported their conceptual development. And how it involved a complex interaction between the bundles of practices in students' lives and how through varied participation in practices students come to write about and recognize how contemporary investigations can give them leverage for potential action outside of the school setting. Learning in the context of the epistemic practices of science involves substantial interaction between the bundles of practice in students' lives and their local learning environments. Culturally expansive, project-based instruction can, in part, facilitate the productive coordination of the practices within these local contexts.

Finally, Chapter 4 built on the work from the previous two chapters under the commitment that students' engagement in scientific practices is an identity-related strategy for supporting learning in practice that has bearing on who one is as an individual and who one sees herself becoming in the future. It explored the characteristics of learning environments and the presence of identity resources for supporting the development of scientific practice-linked

identities (Nasir & Hand, 2008). Arrangements of learning setting characteristics—access to the domain, roles and accountability, and space to make meaningful contributions—along with practice-linked identity resources that arose from interactions in the learning setting supported learners in stabilizing practice-linked science identities through their engagement in contemporary scientific practices.

Across the three studies, four high-level conclusions can be drawn from the work as described below.

**Conclusion 1: Classroom learning environments can support students' participation in authentic epistemic practices through contemporary, interdisciplinary science investigations and support their deepening participation through interest-driven learning as students leverage their prior expertise, interests, and identities.**

Interest-driven learning about professional work from the world is a powerful way to motivate deeper engagement and learning for students. This type of learning environment can be designed for classroom settings in which learners see coordination across the practices of their lives and therefore, “They have less disjuncture to overcome before their curiosity, trust, and willingness lead them to learn something new” (Heath, 2012a, p. 256). In these kinds of experiences, students have the opportunity to engage in subject matter learning and performance of epistemic practices in ways that leverage their existing expertise, identity, and interest and also open up spaces for them to creatively design and conduct investigations with meaningful goals. As discussed in Chapter 3, students were able to design investigations informed by their own interests and/or a greater societal issue and then explain the relevance of their investigation drawing from background research they conducted, thus deepening participation and knowledge of the context of the work. Student learning in the classroom can be meaningfully connected to

practices that occur in other settings; this work detailed how students made these connections by hypothesizing about the impacts of their investigation outcomes on practices in other settings and how it was similar to that of other scientists.

Through teacher-researcher collaborations, the yearlong biology curriculum was implemented at a greater scale across six schools, 375 students, and seven teachers with varying local contexts and circumstances. Although the uptake of the intervention in local contexts presented different dilemmas and solutions for teachers, all teachers were able to support their students' participation in scientific practices in meaningful ways and reported increased, and often surprising, levels of engagement from their students throughout the school year.

Implications for design of learning environments in school settings arise from this conclusion. Students are able to do real scientific project work in the classroom. As a design strategy, finding opportunities for students to do real work from the professional scientific world requires exploration of options and collaboration with STEM professionals coming from a stance on learning that students are capable of engaging in such work. Given the multiple arrangements of interests and identities that students bring into the classroom, learning environments should be designed with multiple entry points for students to see their interests and expertise informing their science work and learning. One strategy is to embed authentic activities, as part of project investigations that engage a range of students by leveraging out-of-school practices (e.g., how the Foldit citizen science gaming leveraged videogaming practices of youth). For teacher-research collaborations, teachers need to be supported in seeing the educational value of these experiences for their students and then in navigating the external demands on them (e.g., high stakes assessments) that often cut into the time needed for project-based learning opportunities.

**Conclusion 2: Scientific practices, school practices, students' interests and experiences, and relevant social domain practices interact and influence how students and teachers experience practice-focused instruction on contemporary science. This allows for tracing student engagement over time.**

Scientific practices cannot simply be “added” to traditional classroom science instruction in some straightforward manner. They will interact with other practices at play in the setting. However, they can also be intentionally connected to other practices in support of science learning goals. The design framework in this study informed the design of a curriculum that tried to make productive connections between scientific practices, school practices, and everyday community practices. Through analysis, a fourth bundle of practices—associated with the work of relevant social domains—was added to account for the ways in which students connect their investigations to broader sets of organizational, institutional, or societal practices.

Asked to engage in multiple, overlapping scientific practices in each investigation, students' performances of scientific practices influenced each other and were traceable across the written products of an investigation. For example, in Chapter 3, students used outcomes of the information practice and the investigation practice to support their arguments for continued funding. Students' arguments also took into account the overarching scientific purpose—arguing for an opportunity to continue the work—and therefore made connections to relevant social domains as a way to communicate the potential implications of their continued work for society more generally. Having students see this kind of authentic purpose in their school work is too rare in science classrooms. Clear linkages to students' everyday expertise interacted with their deepening participation in the scientific practices. This supported the stabilization of practice-linked identities for youth in the context of contemporary scientific practices. This interaction

was bidirectional; either initiating the deepening of participation or the exposure to contemporary scientific practices opened up space for the connection to everyday expertise. In order to support this deepening participation, teachers used their own knowledge of the local areas and consulted local experts to connect the scientific practices to local places and issues.

Curriculum designers should intentionally support productive interactions between the four bundles of practices in support of student engagement and learning. In addition, an implication for the curriculum design community is the need for educative curricular materials that support teachers in recognizing and mediating points in which school practices might hinder students' opportunities for engagement in scientific practices, as well as recognizing where they can leverage local resources to connect the students' work to the local community. In terms of implications for learning theory, our accounts for what counts as meaningful and consequential for students need to go beyond finding value in local places to understanding how learners come to see value in broader social domains when they make these connections and see how their work in the science classroom is potentially relevant to the outside world.

**Conclusion 3: Opportunities for learners to engage in practices to make a unique contribution is a key feature of learning environments that support students' engagement in epistemic practices and their development of practice-linked identities in science.**

Students still frequently view the assignments of school as sets of meaningless demands (Bruner, 1971), but project-based instruction can help students see the broader purpose by focusing them on producing products or knowledge that is consequential in a broader social context. In this study, students frequently recognized relevant social domains as contexts of potential application related to their investigations—in which their investigation outcomes could provide information for changing, uncovering, or informing practices in those domains. For example, one group

designed an investigation to DNA barcode the feathers at the bottom of bird cages at the local pet store to see if they could uncover birds being sold under different names and they related to this to the prevalent illegal parrot trade. Another group examined the biodiversity of a local park to see if there were invasive species common to the region in that park.

For Heath (2012b), informal environments can present opportunities for youth to be “drawn into creative projects that required their sustained commitment, dedicated imitation and practice, and a curiosity that pushed them to know and do more” (p.103-104). These included complex interactions with adults that increased meaningful production through interaction with various audiences and experience with various roles. In this study, students interacted with disciplinary experts to complete investigations that included production of written artifacts and presentations that had meaningful outcomes for the local community and/or broader social domains. Consequentiality varies by learners and disciplines but when learners are given space to be creative, they are able to push the boundaries of contemporary scientific practices.

A consequential, culminating performance that learners care about—with professional values in play and an authentic audience for the work—is a crucial design principle for project-based learning environments, especially those in formal learning settings. Schools that want to improve students’ access to opportunities for consequential production can start to move the school’s open culture towards developing relationships with groups of disciplinary professionals and inviting them to help build the experiences from initial project design moments to attending students’ culminating performances.

Importantly, this opportunity for consequential production of knowledge, products, or performances is a characteristic of the learning environment known to be key for supporting access to and uptake of practice-linked identities (Nasir & Hand, 2008). In Chapter 4, I found

these characteristics, along with access to identity resources in school settings, gave students opportunity to take up to practice-linked identities and expert or leader positions in the class. For designers, the implication is that curriculum should be designed to help learners learn about new kinds of people and work in the world in order to provide multiple entry points based on their interests and expertise. Interactions between students' interest and expertise and opportunities for deepening participation allow them to engage them more deeply in the scientific work and help them affiliate with, and get networked into, communities of practice.

**Conclusion 4: In terms of broadening participation in STEM, there is social value in equalizing access to the human and material resources needed to build powerful learning environments that increase students' opportunities for engagement in contemporary scientific practices. Intensive teacher and researcher collaborations are an important organizational strategy for promoting educational equity in science education.**

Across the yearlong teacher-research collaboration, teachers saw the value in increased work and time commitment for implementing an ambitious contemporary science project-based learning curriculum because they believed students were gaining invaluable experiences through their participation in the work. This awareness arose from their students' high engagement, sometimes staying after school or going to great lengths to gain expertise above and beyond what was expected of them. Students made connections to the value of their work beyond the school context and learned about the realities of scientific work—especially related to the complex arrangements and pursuits that allow for creativity and failure in investigations—in ways that were contrary to their experiences in traditional science instruction. Students typically develop their understanding of science from a series of confirmatory labs or memorization-focused

instruction. The students in this study developed an authentic understanding of how professional science works by being asked to engage in such work themselves.

The learning environment also supported opportunities for scientific literacy, as well as access to and ideas about STEM careers through opportunities provided for entry into practice-linked identity stabilization pathways. For example, learning about the kinds of persons who do science, seeing science as a field filled with creativity and problem solving, and reconciling science with the other identities they bring to the work. Opening up settings to provide access to practice-linked identities can happen through ambitious project-based instruction.

Implementation of ambitious instruction is necessarily a local coordination and resource management issue. Access to material identity resources that allow students to deepened participation with the tools and techniques of the domain can lead to opportunities for practice-linked identity development. Efforts need to be made to support teachers to provide youth from high-poverty communities with these kinds of learning experiences, if we are to broaden participation in STEM learning at scale. Dilemmas arise in reform implementation when features of the reform (e.g., the need for material resources to enact) interact with the histories, instructional practices, and local contexts. In support of educational equity, collaboration of teachers and researchers with diverse expertise and access to instructional resources is one important strategy to pursue. New knowledge needs to be created about the dilemmas and affordances of bringing this kind of ambitious instructional model to scale across a variety of educational organizations and how a co-design group of teachers and researchers can develop and share dilemma management strategies for implementation and to support professional learning.

## **Future Research**

**Instructional model and learning research.** There is more to be done related to attending to the practices of youth and communities and how to support the deliberate coordination of scientific practices with the multiple other identities students bring to learning environments. This could be accomplished through developing embedded measures and analytics that could be used to make participation and identification more readily available for research and instructional purposes. For example, rapid and repeated culling of students' reported interests across time in a way that maps to the instructional goals and unfolding project work would allow for identification of opportunities for creating access points into practice-linked identity stabilization. Relatedly, this work potentially informs the development of more broadly useful classroom-formative assessments focused on the connections students are making between the bundles of practices at play in the science classroom and their everyday and community practices. These formative assessment could identify and trace practice-linked interest and identity stabilization over time. The case studies in Chapter 4 highlighted different processes by which this happened for youth. Also, an additional possible identity coordination study could look at the function of language within discourse related to science learning environments especially around wet-lab work and students' engagement in games for learning to further understand the kinds of language used in the context of productive engagement in scientific work. This would help educators and researchers interpret and guide student engagement.

The implications of the study indicate the importance of local involvement in the scientific work; more research needs to be done on how local community members can get instrumentally pulled into the project work of youth in a sustainable and relationship-building fashion. In a related way, with the connection to local contexts being vital to students'

engagement in scientific practices, what would this instruction and collaboration work look like in a very different context (e.g., in a developing nation context or in an afterschool program context)?

**Research on scaling powerful learning environments.** There is more research and collaboration work to be done to take this kind of ambitious model to scale—working across different kinds of contexts and networks, as well as building lasting collaborations between the same teachers and researchers over multiple years in a way that allows for seeing professional learning and improvement in implementation across larger timescales and networks of people. Growing the network of collaboration to include districts and school networks would allow for learning how to develop human capacity for this kind of instruction at the district or school network level. Research might focus on such questions such as:

- How can you build teacher capacity over time to support greater learner and teacher agency in scientific practice-focused instruction?
- What are productive professional learning pathways for teachers with different expertise, local contexts, and social networks?

All students should be able to learn about and consider learning more about the knowledge and practices associated with STEM fields whether or not they intend to pursue a career in a STEM field. This does not currently happen given how society has arranged educational experiences for youth in this country. As a whole, this study shows that providing students with the tools and means of contemporary scientific inquiry allows them to gain conceptual development and proficiency with scientific practices within the contexts of students' lives, in ways that provided access to resources that promoted students' stabilization of practice-linked identities. For teachers, implementing this instructional model in their classrooms brought up dilemmas and

opportunities in the contexts of their schools and instructional practices. Overall, it is possible to implement and begin to scale curriculum interventions that increase students' access to the knowledge and practices of the STEM fields.

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## Appendix

### **Appendix 1: Conjecture Maps for Scientific Practices Engagement and Scientific Practice-linked Identification**

The studies in chapters three and four stem from the design of a learning environment intended to support students learning through engagement in contemporary scientific practices and to provide opportunities for uptake of scientific practice-linked identities. The conjecture maps provide initial starting points that join the design and theoretical ideas in the learning environment. The maps are meant to “clarify how a research team views the concurrent effort of practice improvement and theoretical refinement” of the learning environment design (Sandoval, 2012, p.3). In this appendix, I lay out conjecture maps related to supporting student practice engagement and student scientific practice-linked identity access within contemporary science curriculum design. These maps lay the groundwork for documenting the design decisions that feed back into the learning environment from testing conjectures using data from these studies.

## Scientific Practices Conjecture Map

To help orient readers to the design place and the outcomes I am interested in related to the students' engagement in scientific practices, I utilize a conjecture map aligned with the focus on scientific practices in curriculum design seen in Figure 1.

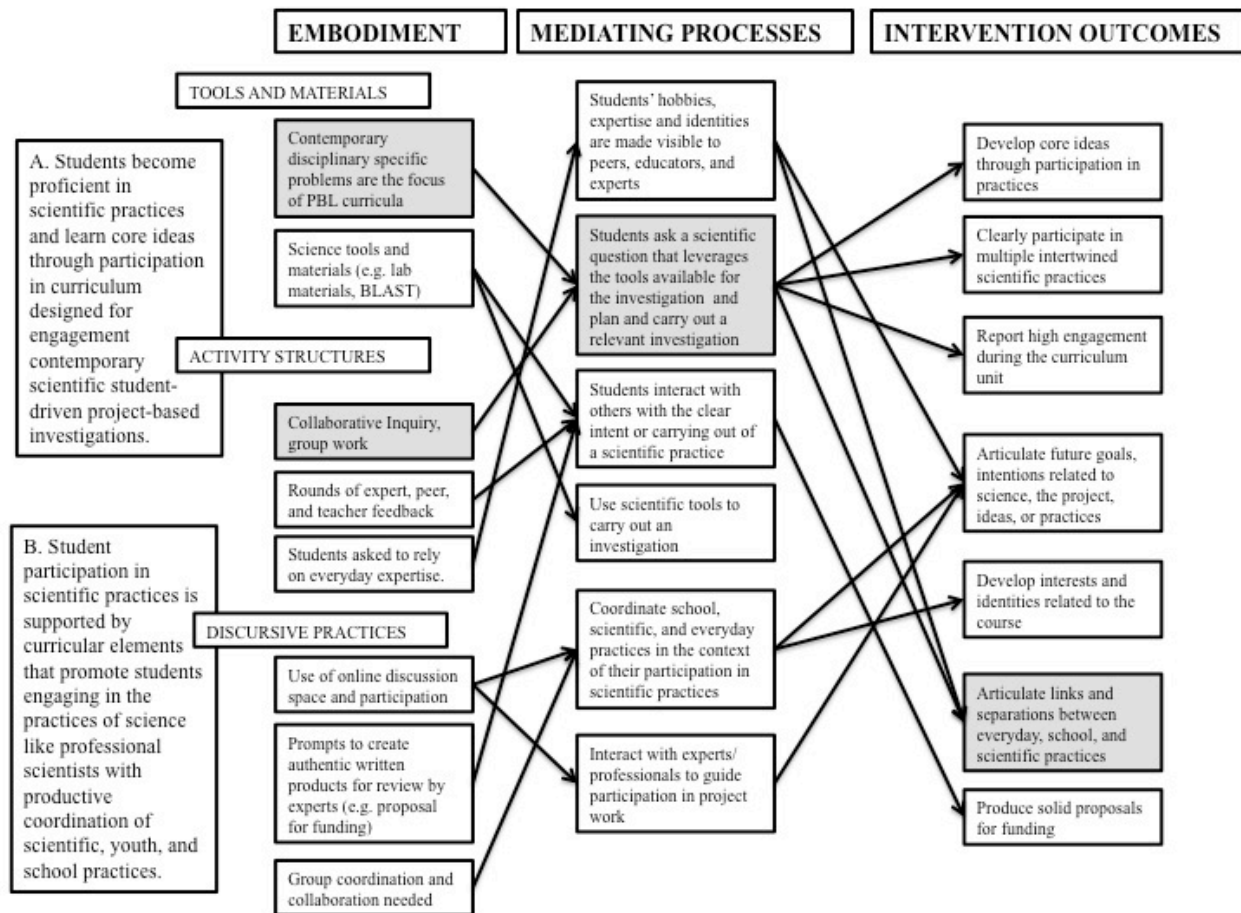


Figure 1. Design conjecture map for participation in scientific practices.

### Conjectures.

- A. Students become proficient in scientific practices and learn core ideas through engagement in contemporary scientific student-driven project-based investigations.
- B. Student participation in scientific practices is supported by curricular elements that promote students engaging in the practices of science like professional scientists with productive coordination of scientific, youth, and school practices.

**Design rationale.** Practice-focused instruction embedded in a project-based curriculum model includes multiple opportunities, performative contexts, and supports to allow students to engage in the practices of science coordinated with the core ideas of the disciplines. The conjecture map outlines the embodied curricular elements under study, primarily, the focus is on asking students to do projects akin to those being pursued by scientists today. *Learning happens in practice at the nexus of the bundles of practices student experience across the moments of their lives. Scientific-practice focused instruction designed as a cascade of overlapping scientific practices in one way to configure learning opportunities to be more like “real” scientific work.*

The recognition and coordination of these bundles of practices (scientific, everyday, school, and relevant social domains) shows up throughout the conjecture map. Conjecture B (see the highlighted path on the map above) may play out through the map as follows: Students focus on contemporary disciplinary specific problems in their PBL projects in a group work activity structure that involves them in the science practices of asking a scientific question that leverages the available investigative tools and planning and carrying out an investigation to address that question. Through this process students — with curricular and teacher expectation that they pursue interest-driven work — may recognize and discuss the links and separations between everyday, school, and scientific practices.

## Scientific Practice-linked Identity Conjecture Map

This conjecture map distills the theoretical assumptions that guided the design work associated with opportunities for practice-linked identity development and stabilization seen in Figure 2.

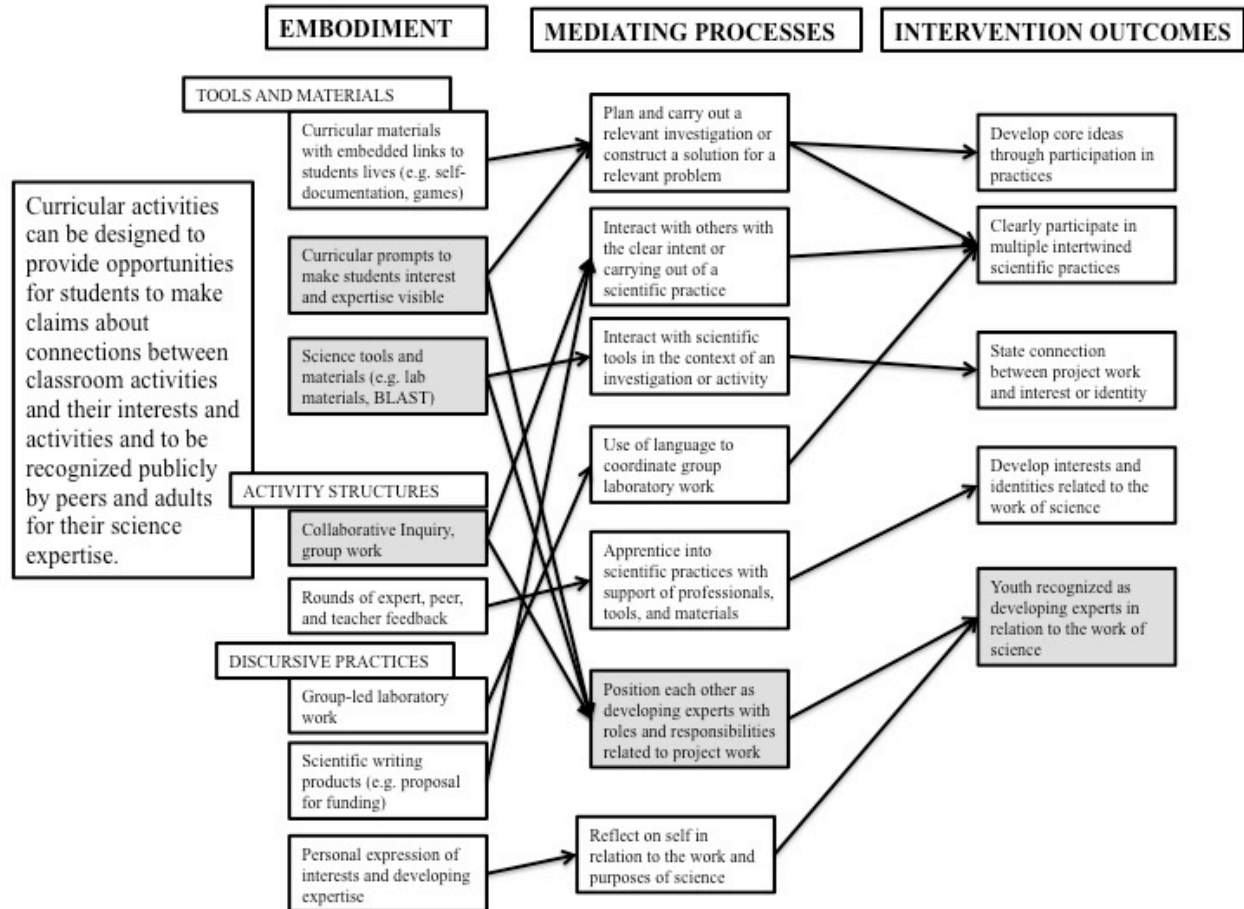


Figure 2. Design conjecture map for practice-linked identity.

**Conjecture.** Curricular activities can be designed to provide opportunities for students to make claims about connections between classroom activities and their interests and activities and to be recognized publicly by peers and adults for their science expertise.

**Design rationale.** Practice-focused instruction occurs in the context of both the curriculum and within the complex lives of students, teachers, and disciplinary experts. Interactions that are designed for and occur in the learning environment have identity implications for learners.

Science identities are bound up in the specific disciplinary practices of science and the

contributing competencies that youth bring to those pursuits. Youth interests can lead to identities that can be stabilized through sustained participation in these disciplinary practices.

*The social identification process occurs as learners gain experiences and engage in interactions that contribute to seeing themselves in the scientific work—what they bring to the work, who they may want to become. Other social actors in the setting also come to recognize learners' developing identities in the midst of the activity.* Given the intertwined relationship between learning and identity and the everyday interactional moments that contribute to both.

For example, with respect to the conjecture (see the highlighted path on Figure 2), if students are participating in collaborative group work with scientific tools and curricular scaffolds, they may experience conditions under which this group work allows them to position each other as developing experts with roles and responsibilities related to the work and those positions could stabilize over time for youth to become recognized as developing experts in relation to the disciplinary practices they engaged in.

## **Reference**

Sandoval, W. (2013). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences*, 1–19.