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High School Biology Teachers' Integration of Argumention in the Context of Disciplinary Literacy Coaching

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HIGH SCHOOL BIOLOGY TEACHERS' INTEGRATION OF ARGUMENTION IN THE CONTEXT OF DISCIPLINARY LITERACY COACHING

by

Ashley Strong

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ABSTRACT

High School Biology Teachers' Integration of Argumentation in the Context of Disciplinary Literacy Coaching

by

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Scientific argumentation is a core practice of scientists and can support student knowledge of science, disciplinary understandings of scientific literacy, and transferrable thinking skills. Scientific argumentation can also immerse students in the doing science rather than learning about science. Scientific argumentation is a complex process that requires students to engage in complex literacy skills such as gathering and interpreting information, composing and supporting claims, and evaluating alternate claims. Integrating argumentation into science courses can be challenging for teachers may not have learned science through argumentation nor received training in how to teach argumentation.

The purpose of this qualitative multiple case study was to identify how teachers who described themselves as novices in teaching scientific argumentation integrated it into their high school biology classes and to understand how the teachers' choices reflected their beliefs and experiences about science education and scientific argumentation. Understanding how teachers with varying experiences and understandings begin incorporating scientific argumentation can provide insight into supporting teachers and ultimately students in scientific argumentation.

Four high school biology teachers of varying years of teaching experience were selected for this study. Teachers participated in disciplinary literacy coaching for three quarters. Data were collected through interviews, audio recordings of classroom instruction and coaching sessions, and artifacts. Data were analyzed using constant comparative analysis. This study revealed several key findings. First, working with disciplinary literacy coach over the course of three quarters, all teachers incorporated argumentation instruction identified in research as having positive student outcomes. Second, teachers' purposes for using argumentation reflected the teachers' instructional choices for scientific argumentation. Third, when teachers' beliefs conflicted with their prior teaching experiences, their experiences aligned more clearly with their instruction for scientific argumentation. Finally, though teachers varied in the amount of argumentation instruction they used, all teachers developed a more complex and nuanced understanding of scientific argumentation and instructional practices to support students. These results highlight potential benefits of disciplinary literacy coaching as a professional development model for complex literacy practices. Additionally, the findings emphasize the importance of beliefs and experiences for in service teachers integrating a new disciplinary practice into their classes.

(317 pages)

PUBLIC ABSTRACT

High School Biology Teachers' Integration of Argumentation in the Context of Disciplinary Literacy Coaching

Ashley Strong

Scientific argumentation is a core scientific practice. Although scientific argumentation has been linked to increased learning of scientific content, improved reading, writing, and critical thinking, traditional science classrooms have not included scientific argumentation. Teachers often have little experience learning or teaching science through argumentation and need support to integrate this complex practice of science into their classrooms. This study compared four high school biology teachers' instruction of scientific argumentation as they worked with a literacy coach. Data were collected through interviews, audio recordings of classroom instruction and literacy coaching sessions, and artifacts. After analyzing the data, several key findings stood out from this study. First, all of the teachers incorporated instruction that research has identified as supportive of student learning of scientific argumentation. Second, the teachers' learning goals or purposes for scientific argumentation informed the decisions they made as they incorporated scientific argumentation. Third, teacher experiences were especially important in teachers' instructional decisions when their beliefs and experiences were contradictory. Finally, all teachers, regardless of the amount of argumentation instruction they incorporated into their classroom developed better understandings of scientific argumentation and best practices to support student learning.

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Ashley Strong

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CHAPTER I

INTRODUCTION

"If we want our students to develop the ability to think critically about scientific evidence, then we must offer them that opportunity. In particular we must break the tie so strongly embedded in the cultural habitus of teaching science that the primary task is to persuade students of the validity of the scientific world view – where experiments are performed simply to confirm the theoretical predictions elaborated by the teacher." *(*Osborne, 2007, p. 179)

Several years ago, I started working with my administration on a project to support teachers in developing literacy instruction in their courses. As part of this project, I was asked to facilitate a discussion about literacy with the whole faculty. I asked each group of teachers, separated by their content area, to find the literacy skills embedded or implied in their state standards. I rotated around the room listening to the drama and choir teacher discuss the skills students needed to transform reading into performance, history teachers discussing the analysis skills students needed to compare primary documents, and math teachers lamenting how students struggled with word problems. I noticed, as I approached the science table, that there was no discussion. One teacher sat back with his arms folded while two other teachers looked at their standards, perplexed. When I reached the table, one teacher announced that there were no literacy skills in their standards anywhere, explicitly or implicitly.

On further discussion, the science teachers realized that standards asking students to research and report, explain, describe, and use specific vocabulary all required literacy skills. This experience stuck with me for two reasons. First, the seemingly resistant science teachers were willing to rethink the ways they viewed and taught their curriculum. In fact, after this conversation, several teachers collaborated with me to develop text sets that they felt were more valuable than traditional science textbooks. Second, the science teachers' beliefs about science and literacy were at such odds, they could not make the connection between their idea of literacy and their ideas about science. This experience, as well as my experiences working with teachers in many disciplinary areas, piqued my interest about the ways teachers view and support literacy practices in their discipline.

This study stems from my time working as a literacy coach, specifically working with teachers to engage students in inquiry and argumentation. I wanted to understand the ways teachers implement a new, complex literacy practice into their instruction and how disciplinary literacy coaching could support them. Additionally, I wanted to understand how teachers' beliefs and experiences are connected to their decisions as they introduce new instructional practices. Furthermore, I wanted to understand whether and how collaboration among teachers with expertise in different disciplines (e.g., my own expertise in English language arts and the teachers' expertise in biology) can expand teacher instructional strategies beyond traditional lecture-based instruction.

Statement of the Problem

Argumentation, generally defined as the process of developing a claim and supporting it with evidence and reasoning (Sampson & Clark, 2008; Osborne et al., 2004), has gained a central role in education standards over the past decade. Policy makers in the United States have included argumentation in standards for language arts, social studies, and science (National Governors Association Center for Best Practices, 2010). More recently, argumentation specifically related to science (scientific argumentation) has been emphasized in the *Next Generation Science Standards* (NGSS, Lead States, 2013) and the Program for International Student Assessment (PISA); both organizations include argumentation skills, such as the evaluation of claims and the use of data, as key practices for students in science contexts (Organisation for Economic Co-operation and Development, 2015). These policies reflect research that has identified argumentation as a core practice of scientists (Duschl & Osborne, 2002; NGSS, Lead States, 2013; Osborne et al., 2016) and an effective method for teaching science (Berland et al., 2016; Osborne et al., 2004; Ryu & Sandoval, 2012; Sampson & Blanchard, 2012; Sampson et al., 2013).

Despite the increase of research in scientific argumentation and the prevalence of argumentation in national standards, many secondary science teachers do not include argumentation in their instruction (Drew et al., 2017; Litman & Greenleaf, 2017; Osborne, 2010). Several possible reasons may explain the paucity of argumentation in secondary science classrooms. First, teachers may not have experience developing quality scientific arguments (Sampson & Blanchard, 2012) and may not have training in instructional strategies to support students' argumentation skills (Zohar, 2007). Argumentation also requires a shift away from traditional science instruction that heavily relies on lectures (Duschl, 2008; Osborne et al., 2004), which may be uncomfortable for teachers "who likely did not learn science through argumentation" (Henderson, et al., 2018, p. 7). Finally, argumentation is a complex process requiring students to develop literacy skills specific to scientific contexts. To engage in the complex process of argumentation, students

> require various kinds of sophisticated literacy skills, including the ability to make sense of scientific terminology; interpret arrays of data; comprehend scientific texts that convey information in 'verbal' expositions, as well as in graphs, tables, visual models, and diagrams; use and interpret models and illustrations; and read and write scientific explanations. (Goldman et al., 2016, p. 230)

Developing such sophisticated literacy skills in students may be a deterrent to secondary science teachers who often feel unprepared to teach literacy, or who see literacy as beyond their purview as science educators (Carnegie Council, 2010; Rush, 2013; Snow et al., 2006). Teachers who incorporate argumentation into their courses may face additional challenges due to the complex nature of argumentation. Fully incorporating argumentation can be a long-term endeavor that challenges both teachers and students (Osborne, et al., 2004; McNeill & Pimentel, 2010).

Because incorporating argumentation effectively can be challenging, teachers may benefit from ongoing support through professional development (PD). PD models may support teachers best when they help teachers gain experience in argumentation instruction, develop instructional strategies for the complex literacy demands of argumentation, and increase their knowledge of quality scientific argumentation. Zohar (2007) suggested coaching models as potential PD for scientific argumentation. Coaching may help teachers see the benefits of argumentation and support them as they develop new methods in their classroom. Because argumentation requires students to engage in complex literacy practices, literacy coaching, a type of job-embedded PD designed to support teachers' literacy instruction, may be a promising model for scientific argumentation.

More specifically, literacy coaching grounded in disciplinary literacy, in contrast to intermediate or basic literacy (Shanahan & Shanahan, 2008), supports teachers as they engage students in reading and writing texts in ways that facilitate disciplinary knowledge and practices (Di Domenico et al., 2018). To support students in these disciplinary literacy practices, literacy experts who know how to support students' reading and writing must closely collaborate with disciplinary experts (such as science teachers) who understand the purposes and practices of reading and writing in their discipline. In disciplinary literacy coaching, "the coach must be an expert collaborator and learner, who positions the teacher as the expert regarding the discipline" (Elish-Piper, et al., 2016, p. 12). Few studies have looked at literacy coaching through a disciplinary lens (Binkley, et al., 2012; Di Domenico, et al., 2018; Wilder, 2014) and none of them specifically focused on disciplinary argumentation. This type of collaborative PD may be a promising model for scientific argumentation because it accounts for the differing expertise of coaches and teachers, while supporting them in developing instructional practices that support students in developing a core disciplinary practice.

Purpose of the Study

The purpose of this study was to understand how high school biology teachers incorporated argumentation into their instruction and to understand how their experiences and beliefs informed their pedagogical decisions within the context of disciplinary literacy coaching. For the purpose of this study, incorporation of argumentation includes the materials teachers created, the methods of instruction teachers used, and the tasks or activities teachers assigned to students in the service of learning skills essential to argumentation or engaging in scientific argumentation. The four biology teachers chosen for this study had taught between two and twenty-four years, but all of the teachers had little to no experience teaching argumentation. By exploring how teachers with varying degrees of teaching experience incorporated argumentation skills for the first time in the context of disciplinary literacy, this study may provide insights into professional learning for teachers that directly addresses national literacy standards for science (National Governors Association Center for Best Practices, 2010; NGSS, Lead States, 2013).

Research Questions

1. How, when, and why do high school biology teachers integrate scientific argumentation into their instruction in the context of disciplinary literacy coaching?
2. How do each teacher's experiences and beliefs map onto their instructional practices related to integrating scientific argumentation?

Significance of the Study

This study was implemented during a year in which the state was introducing new science standards that focused on disciplinary practices such as argumentation. This shift in standards reflects national guidelines for science instruction (NGSS, Lead States, 2013) and research recommendations to support students in learning the literacy and language practices of science (Hand et al., 2003; Lemke, 1990; Osborne et al. 2004; Yore et al., 2003) which emphasizes scientific ways of thinking, including argumentation. For teachers, however, these changes are a departure from traditional ways of teaching. This study can provide insights for districts and administrators as they develop PD to support teachers in adjusting their teaching in light of these new standards. This study also provides research on how literacy coaches at the high school level can support teachers to help them transform their instruction to meet science and literacy standards and ultimately elevate student learning.

Research has pointed to the benefits of science instruction for students in conceptual understandings of science (Venville & Dawson, 2010) and improving argumentation skills (Sampson & Clark, 2008). For teachers to leverage these benefits in the science classroom, we need an understanding of how teachers practice potentially unfamiliar instructional strategies and how their experiences ad beliefs inform their instructional choices. Argumentation in science classrooms often requires a significant change in the practices and procedures of a traditional transmission model of instruction (Zohar, 2007), yet research in PD in both secondary schools and science argumentation is limited (Reed, 2009; Zohar, 2007). This study adds to the existing literature on PD in science argumentation by specifically focusing on how teachers implement new instructional practices in the context of disciplinary literacy coaching. In understanding how teachers integrate new literacy practices in the content area, researchers and practitioners can build on this information to support students' disciplinary literacy skills.

Definitions of Key Terms

Argument: The product created through argumentation (Osborne et al., 2004).

Argumentation: Generic process of creating and supporting a claim or position that can be applied to many subject areas.

Argumentation Unit: One or more argumentation activities focusing on the same topic or question.

Basic Literacy: Literacy skills that are necessary for all reading tasks "such as decoding and knowledge of high frequency words" (Shanahan & Shanahan, 2008, p. 42).

Beliefs: "Psychologically-held understandings, premises, or propositions about the world that are felt to be true" (Richardson, 1996, p. 103) and that are presumed to direct actions and practices (Bryan & Atwater, 2002).

Claim, Evidence, Reasoning (CER): A structural definition of arguments consisting of a claim, evidence that supports the claim, and reasoning linking the evidence to the claim (McNeill & Krajcik, 2011).

Collaborative Coaching Cycle: This cycle leads teachers and literacy coaches through a reiterative cycle of planning, teaching, and reflecting (International Literacy Association, 2018). Specific elements of the coaching model are listed below.

Collaborative Coaching: Coaching in which a literacy coach and a teacher or group of teachers co-create instruction to support students' literacy skills. Collaborative coaching can take place between a single coach and teacher, a coach and a group of teachers, or a combination of individual and group collaboration. This study relies on a combination of individual and group collaboration (Elish-Piper et al., 2016).

Collaborative Group Coaching Session: A small group of teachers facilitated by a literacy coach who collaborates with teachers to plan and reflect on specific instructional strategies.

Disciplinary Literacy Coaching: Coaching in which a discipline expert and a literacy expert collaborate to identify disciplinary literacy practices and develop ways to teach students these strategies (Di Domenico et al., 2018).

Disciplinary Literacy: Literacy skills that help students practice disciplinary habits of mind as they interpret and create complex texts in ways that enhance disciplinary goals (Moje, 2007).

Individual Coaching Session: A one-on-one meeting between a literacy coach and a teacher focusing on implementing instructional strategies, discussing observations of instruction, and reflecting on ways to improve instruction.

Intermediate Literacy: Generic literacy skills that can be applied to many tasks such as comprehension strategies and fluency (Shanahan & Shanahan, 2008).

Modeling Coaching Stage: A coaching stage in which a literacy coach demonstrates how to teach a lesson. The teacher observes the coach with the intention of using the same instructional strategies in a future lesson.

Next Steps Coaching Stage: A coaching stage in which the teacher and coach identify the next steps for instruction. This could include reteaching a skill, building on a skill in a new lesson, or developing new instructional strategies to address problems in the instruction.

Pedagogical Content Knowledge (PCK): Understandings of the best "ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9) including knowledge of instructional strategies (McNeill & Knight, 2013).

Planning and Goal Setting Coaching Stage: A coaching stage in which literacy coach collaborates with teachers to develop standards-based learning goals for students, sequence instructional strategies, and plan for ways to support struggling students.

Reflection Coaching Stage: A coaching stage in which the literacy coach leads the teacher to reflect on areas of strength and needs for improvement in a recent lesson. The literacy coach may direct the teacher to a specific moment of instruction or examine student work.

Scientific Argumentation: Argumentation "consistent with the epistemological criteria used by the larger scientific community" (Sampson & Clark, 2008, p. 448) such as generating claims that cohere with scientific principles and collaboratively critiquing and debating to identify the best explanation based on existing data.

Student-Centered Instruction: Instruction in which students construct skills and understandings with support or guidance from the teacher (Serin, 2018).

Teacher-Centered Instruction: Instruction in which the teacher makes sense of the content for the students (Granger et al., 2012).

Team-Teaching Coaching Stage: A coaching stage in which the teacher and coach work together to teach a lesson, planning out each of their roles in advance.

Toulmin's Argument Pattern (TAP): A structural definition of arguments consisting of a claim, data that support claims, warrants, backings, and rebuttals (Toulmin, 1958).

CHAPTER II

LITERATURE REVIEW

Scientific argumentation has received increasing attention as an important practice in science education reflected in world-wide education policies that have incorporated argumentation into curriculum (Jiménez-Aleixandre & Erduran, 2007) and an increasing body of research on argumentation in science education (Erduran et al., 2015). However, in the current literature, scientific argumentation has been interpreted in multiple ways. Similarly, scientific argumentation has been enacted in many ways both by teachers and researchers. Such variation in both research and practice might be explained by the fact that scientific argumentation is a complex task asking students to engage in multiple and varied literacy skills. The purpose of the following review is to summarize the research describing the product of arguments and the practice of argumentation in science and to discuss what research currently says about supporting teachers and students in argumentation including research on disciplinary literacy coaching as a professional development (PD) model for scientific argumentation.

Theoretical Framework

Literacy coaching to support teachers as learners is grounded in sociocultural learning theory (Lave & Wenger, 1991; Wenger, 1998) that describes learning as centered in social interactions and experiences. Literacy coaches have many different roles, including collaborators, job-embedded mentors, evaluators of students' literacy needs, and instructional strategists (International Literacy Association [ILA], 2006).

Literacy coaches often plan and discuss student learning and instruction with individuals or groups of teachers, emphasizing the social component to teacher learning. Several studies (Gross, 2012; Lockwood et al., 2010; Mangin & Dunsmore, 2015; Marsh et al., 2010) have framed coaching in terms of Lave and Wenger's (1991) concept of apprenticeship, which describes how a novice learner is supported by experts in a new community. In these studies, the coaches were presented as the experts and the teachers were the novices who progressed toward full membership in a community.

This framework can be problematic for coaching in secondary schools because literacy coaching at the secondary level must focus less on generic literacy skills such as decoding text, or applying comprehension strategies, and more on developing literacy skills appropriate for using and creating complex texts specific to a discipline (ILA, 2018). Coaches may not be experts in all disciplines, and all teachers are not novices in instruction. In recognition of this distributed expertise, Gallucci et al., (2010) argued for a framework for literacy coaching that incorporates Wenger's (1998) concept of communities of practice, claiming that the coach is not simply passing on wisdom to teachers, but is negotiating meaning with teachers who are engaged in the same purpose as the coach. Communities of practice (CoP) may be a more appropriate framework for disciplinary literacy because a disciplinary literacy coach situates the teacher as the disciplinary expert.

Communities of Practice and Professional Development

Wenger (1998) argued that learning is made up of the following components: meaning, practice, identity, and community.

> 1) Meaning: a way of talking about our (changing) ability – individually and collectively – to experience our life and the world as meaningful. 2) Practice: a way of talking about the shared historical and social resources, frameworks, and perspectives that can sustain mutual engagement in action. 3) Community: a way of talking about the social configurations in which our enterprises are defined as worth pursuing and our participation is recognizable as competence. 4) Identity: a way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities. (p. 5)

These components interact with each other as people engage in CoP. We are simultaneously members of multiple communities at once, and these memberships influence our identity and our practices in different communities. Wenger (1998) noted that "learning means dealing with boundaries: it creates and bridges boundaries; it involves multimembership in the constitution of our identities, thus connecting – through the work of reconciliation – our multiple forms of participation as well as our various communities" (p. 227).

Teachers are often members of multiple communities within the larger community of education, and so they constantly negotiate their practices in response to different communities. Teachers may be members of the larger disciplinary community of science, for example. Novice teachers may have formed a community of practice with other novice teachers in their schools. Teachers may be engaged in a community of practice with other teachers who teach their specific course, such as biology. A biology teacher, who is also a football coach, may introduce practices from his athletic coaching community to the practices of biology teachers. Teachers from many content areas may form a community of practice centered on improving their classroom management. As these teachers work toward a common goal, the practices of art teachers, for example, might become a common practice of this new community. As teachers work together for a common goal in one community, they may introduce practices from other communities.

Wenger's CoP (1998) has been used to examine teacher learning in multiple contexts. Cuddapah and Clayton (2011) used the CoP framework in examining how 15 novice teachers teaching grades K-12 developed as a community without the clear support of an expert or mentor. They emphasized the multiple CoPs that teachers can participate in at the same time. These teachers "peer-mentored as opposed to being on the receiving end of a mentor-mentee relationship" (Cuddapah & Clayton, 2011, p. 72) which positioned these novice teachers as having valuable contributions to the community. Cuddapah and Clayton described the teachers as being more open to asking questions and sharing vulnerabilities. Because the teachers taught different grades at different schools, Cuddapah and Clayton described the teachers as incorporating practices from outside communities into this new community, bounded by their shared interest of improving their instruction as beginning teachers.

Similarly, Coskie and Place (2008) used CoP for investigating elementary school teachers who participated in the National Board for Professional Teaching Standards. In observing these National Board-Certified Teachers (NBCTs) in their schools after participating in this program, Coskie and Place found that the participation of these teachers in multiple communities—including their schools, their collaborative teams, and their membership in the National Board community—were often in conflict. In some cases, this conflict caused teachers to adapt their practices in ways more aligned to their school CoP. In other cases, "the same discontinuities provide an opportunity for NBCTs to act as 'brokers' between the National Board community and the communities of their schools" (Coskie & Place, 2008, p. 1904).

Both of these studies emphasize the negotiated meaning that teachers must make as members of multiple CoP (Wenger, 1998). In the case of disciplinary literacy coaching, teachers co-construct a new community with literacy coaches, much as the novice teachers in Cuddapah and Clayton's (2011) study, but they also maintain their roles in CoP associated with their discipline, in the case of this study, the science department or biology educators. In joining a new community focused on a specific learning goal, both the teachers' and the literacy coach's membership in other communities may influence the ways they interact and create common practices in this new community. Also, like the National Board teachers in Coskie and Place's (2008) study, these teachers may become "brokers" for other science teachers in their departments, or they may face challenges in maintaining new practices (e.g., methods used to teach argumentation) if they experience conflict with their membership in another CoP. PD programs in schools have not always taken teachers' multi-membership into account when creating learning activities.

Classrooms as Communities of Practice

Additionally, CoP is also appropriate for looking at the classroom as a community itself. Like PD which often positions the teachers as novices, classrooms have often presented classrooms as having an expert (the teacher) apprenticing a group of novices (students). This framework also overlooks the variety of communities students participate in, including the community of being a secondary student, or the communities they engage in outside of school. Students, like teachers, also participate as full community members in other areas and negotiate their roles as learners with the teacher in any given classroom (Berland, 2011). The classroom, then, can be understood as a CoP in which the teacher and the students negotiate the meaning, and the purpose of the classroom community. For example, students may view the main purpose of the class to get a good grade whereas teachers may view the main purpose of the class for students to learn. These goals may be negotiated by both the students and the teacher. The teacher's language may change from discussing what students should learn to how many points a given assignment may be worth, or the teacher may emphasize that something will be on the test that makes up a large percentage of the students' grades. This can be further compounded in secondary schools because students do not engage in a single CoP throughout the day. Students are asked to engage in CoPs as language arts learners, science learners, athletes, and more. Students must bridge these varying CoPs as they work with different teachers and students in each class. Acknowledging that students may bring understandings of practices such as argumentation from other CoPs can be an important element to understanding how and why teachers incorporate argumentation into their classroom.

Summary of Theoretical Framework

Viewing PD from the perspective of a CoP (Wenger, 1998) can provide insight into how and why teachers implement new instructional practices in the ways they do. By understanding how groups of teachers negotiate their ways of talking through their multiple membership in communities of practice, researchers may gain some insight into why teachers might resist certain types of instruction, or the ways they might adapt ways of talking about instruction for fellow teachers. Similarly, understanding that teachers engage with students in a community of practice may provide insight into how and why teachers present new skills to students in particular ways.

Review of Empirical Literature

In this literature review, I first examined the literature related to literacy coaching as a PD model in secondary schools. Below, I begin by discussing the literacy coaching model of PD before examining the literature on challenges in secondary literacy coaching, effects of literacy coaching on teacher beliefs and practices, and the characteristics of effective literacy coaching. The purpose of examining literacy coaching at the secondary level is to identify how literacy coaching has been used at the secondary level and to identify areas of need in the research of disciplinary literacy coaching for specific literacy practices.

I also examined the literature related to scientific argumentation as an instructional practice. I begin by examining the benefits of scientific argumentation on student learning before examining the ways scientific argumentation has been defined in research. The final sections of this review describe literature on teacher experiences and beliefs, instructional practices that have led to positive student outcomes, and research on PD specifically in scientific argumentation.

Literacy Coaching Model of PD

The coaching model of PD has become more popular in both elementary and secondary schools since Joyce and Showers (1980) developed a peer-coaching model to improve on the existing pull-out PD models. In their model, Joyce and Showers initially described peer coaching as a combination of modeling, practice, and feedback. They later expanded peer-coaching to emphasize collaborative work in creating and evaluating instructional practices. Literacy coaching quickly developed out of this framework and gained popularity initially in elementary schools. Funding for literacy coaching in states like Florida in 2001 and Wyoming in 2006 extended the popularity of literacy coaches into middle and high schools (Lockwood et al., 2010; Rush, 2013).

Literacy coaches can take on a variety of roles including skillful collaborators, job-embedded coaches, evaluators of students' literacy needs, and instructional strategists (International Literacy Association, formerly International Reading Association, 2006). While literacy coaches may take on a variety of roles, collaborative coaching has been frequently reported as the most common method of coaching (Blamey et al., 2008; Campbell & Sweiss, 2010). Though the term collaborative coaching has consistently been used as an alternative to supervisory coaching roles, the term has been used to describe a variety of PD configurations. First, collaborative literacy coaching has described a collaborative relationship between a single literacy coach and one teacher (Di Domenico et al., 2018; Fisher et al., 2011; Ippolito, 2010). Additionally, it has been used to describe small groups of teachers who regularly meet with each other (often in school departments) and a literacy coach to improve aspects of their reading and writing instruction (Joyce & Showers, 2002; Rush, 2013). Few studies have explicitly looked at collaboration of a group of teachers in addition to one-on-one collaboration, though some have implied that this was part of the coaching procedures (Rush, 2013; Strahan et al., 2010). Both elements of collaborative coaching align with characteristics of effective PD, notably job-embedded opportunities for collaboration and active learning over a sustained period of time (Darling-Hammond et al., 2009; Desimone, 2009; Garet et al., 2001; Reed, 2009).

Challenges to Literacy Coaching in Secondary Schools

Literacy coaching is often described as job-embedded training that helps teachers implement new practices and skills in the context of the classroom and has frequently been used as a component of a larger PD model (Joyce & Showers, 2002; Kraft et al., 2018). Notably, research on literacy coaching (Blamey, et al., 2008; Rush, 2013) has been largely centered in early childhood and elementary settings. However, many of the challenges and practices of coaching in secondary and elementary schools overlap, such as balancing administrative directives or evaluative goals with relationship building (Ertimer et al., 2005; Ippolito, 2010). Some researchers (Ertimer et al., 2005; Sturtevant, 2003; Sturtevant & Linek, 2007) have also recognized that coaching in secondary schools, especially high schools, is different than coaching in lower levels, and teachers and students at this level operate in different contexts with unique challenges.

One unique challenge of literacy coaching at the secondary level is that teachers need to be supported in addressing complex literacy practices in each content area, especially in high schools. In high school settings, students are expected to read longer, more complicated disciplinary texts independently (Snow et al., 2006). Some students who may have basic reading proficiency may not have had opportunities to learn how to navigate the demands of disciplinary texts (Fang et al., 2014). Teachers may not have the experience or training to support students in developing these disciplinary reading skills, especially content teachers whose preparation programs centered more on content than literacy or language development (Greenleaf et al., 2001). Research about the ways literacy coaching can help content area teachers support students in the language practices of their discipline is limited (Di Domenico et al., 2018). Most of the growing research in secondary literacy coaching has looked at general literacy skills such as students' reading scores on state exams or basic literacy skills (Allen et al., 2015; Edwards et al., 2015; Lockwood et al., 2010; Lovett et al., 2008), included literacy practices more aligned with content area reading skills rather than discipline specific practices (Cantrell et al., 2009; Edwards et al, 2015; Gross, 2012), or not provided enough description of the PD to identify disciplinary specific support (Collet, 2012; Konza & Michael, 2010; Stevens, 2010).

Studies that have looked at disciplinary literacy instruction show some promise in disciplinary literacy coaching for changing teacher practice. Wilder (2014) described a case study in which a literacy coach with a language arts background used his own limitations in understanding high school mathematics to help the teacher think about the problems students may be having with comprehension. Similarly, Di Domenico et al. (2018) described the ways a literacy coach questioned teachers in social studies, English, and mathematics to draw out disciplinary knowledge the teachers may not have been conscious of. These studies highlight the ways disciplinary literacy coaching may support teachers as they incorporate new instructional strategies, but more studies are needed in other subject areas to fully understand how disciplinary literacy coaching can support teachers in changing their practices, especially when the coach is a disciplinary outsider. Additionally, few studies have focused on a specific disciplinary literacy practice such as scientific argumentation, which may require significant restructuring of classroom practices.

Another well-documented challenge in secondary schools is resistance from secondary teachers to change their practices, especially in disciplines such as science, (Carnegie Council, 2010; Rush, 2013; Snow et al., 2006). For example, Cantrell et al. (2009) interviewed 28 middle and high school teachers in math, science, English language arts, and social studies about literacy PD, and 82% of them reported feeling anxious and resistant to implementing new literacy skills into their classrooms. Cantrell et al. only reported overall responses without identifying the subject area taught, but the anxiety reflected in this small survey is reported in other studies with middle and high school teachers from a variety of subjects (Rush, 2013; Stevens, 2010).

One possible reason for teacher resistance to literacy coaching may be related to teachers' beliefs about education. To develop disciplinary habits of mind, including using literacy skills to interpret and produce complex texts, students need support to actively make meaning from disciplinary texts. This kind of teaching centers the class around student knowledge construction rather than teacher-centered transmission of knowledge. Teachers who see transmitting content to students as the main purpose of their course may view literacy instruction as unrelated to their course or unfamiliar as an instructional method (Ertimer et al., 2005; Gross, 2012; Rush, 2013; Stevens, 2010). These beliefs may be related to educational movements that encouraged all content-area teachers to stop teaching their content and teach reading strategies unrelated to the rest of their curriculum (Ippolito & Lieberman, 2011). Such approaches, commonly referred to as "content-area" literacy, often focus on school-wide literacy initiatives that ask all teachers to teach students the same general reading strategies even though the strategies may not be appropriate for the types of texts or purposes in the discipline (Shanahan & Shanahan, 2008). These trends in education may be one contribution to teacher beliefs about the role of literacy in their classroom but may also be related to beliefs about their subjects in general.

Teacher resistance to literacy coaching may also be associated with a lack of confidence in the coach or a lack of understanding of the role of the coach (Campbell & Sweiss, 2010; Dimeglio & Mangin, 2010; Kraft et al., 2018). Researchers (Binkley et al., 2012; Ertimer et el., 2005; Feighan & Heeran, 2009; Gallucci et al., 2010; Gross, 2010) have frequently described coaches as expert teachers who transition to a new role in the same school or district, and many of them come from reading or English language arts backgrounds (Brinkley et al., 2012; Gallucci et al., 2010; Wilder, 2014). When these coaches work in disciplines outside of their teaching experience, teachers may view them as outsiders (Wilder, 2014). This may be exacerbated when literacy coaches also feel unfamiliar with content knowledge. Campbell and Sweiss's (2010) study, in which 111 high-school coaches were surveyed, confirmed that many coaches experience discomfort with certain types of content knowledge. These literacy coaches reported the most familiarity with language arts and social studies and reported spending less time coaching science and mathematics teachers. Calo et al.'s (2015) survey of K-12 literacy coaches found that many were not comfortable working with teachers outside of language arts, but they did not report how many of these teachers were in elementary, middle, or high school settings.

Despite coaches' reported discomfort working with some subject areas, many studies on coaching in secondary schools do not address the ways coaches may have to adapt their coaching to meet the specific needs of different subjects. Research has often ignored the way a coach's background might influence teachers. In multiple studies

(Binkley et al., 2012; Di Domenico et al., 2018; Gallucci et al., 2010; Wilder, 2014), coaches are often described as former teachers with literacy or English language arts backgrounds. In many other studies (Allen et al., 2015; Cantrell & Hughes, 2008; Chiola, 2016; Edwards et al., 2015; Lockwood et al., 2010), coaches are not described at all. This has led to an understanding of a coach as infallible rather than a human component in the coaching model (Gallucci et al., 2010).

Effects of Secondary Coaching on Teacher Practices and Beliefs

PD is necessary to support teachers who may have had insufficient training or experience in supporting students' literacy and language development (Greenleaf et al., 2001). Part of this PD must address teacher beliefs about their own role in literacy development (Zohar, 2007). Additionally, effective PD should help teachers develop new practices with collaborative support from other teachers and feedback from mentors (Reed, 2009). Literacy coaching has been linked to changes in both teacher beliefs and changes in practice, but researchers need a better understanding of the contextual and individual factors that may play a role in the way coaching changes teachers' practice.

Research looking at teacher attitudes and beliefs in the context of literacy coaching has reported increased level of confidence in literacy instruction. For example, Cantrell and Hughes (2008) measured 22 junior high teachers' self-efficacy about literacy instruction before and after participating in a PD with monthly coaching. The teachers taught science, math, English language arts, social studies, and reading. Teachers reported their personal efficacy (beliefs about their own role in improving literacy), general efficacy (beliefs about education's role in improving literacy), and collective efficacy (beliefs about their school environment's role in improving literacy). Teachers' beliefs in their own abilities in teaching literacy strategies grew the most at the end of the study, and all three levels of efficacy were reportedly significantly larger than prior to the PD. The teachers described student engagement, modeling, and discussions with coaches as fundamental in increasing their self-efficacy in literacy instruction. Other studies (Feighan & Heeren, 2009; Fisher et al., 2011; Lovett, et al., 2008) have described similar themes of increased confidence and self-described ability to improve student literacy skills in response to literacy coaching.

Although a sizeable body of research indicates that literacy coaching increases teachers' sense of efficacy in teaching literacy strategies, research examining literacy coaching's role in increasing teachers' pedagogical knowledge has been less consistent. In some studies (Fisher et al., 2011; Cantrell et al., 2009), teachers reported a better understanding of the long-term support students need to develop literacy skills. Edwards et al. (2011), however, did not find a difference in teacher knowledge of comprehension strategies compared to teachers in non-coached schools. One limitation in this study, however, was the length of time teachers worked with coaches and what took place in the coaching sessions. Notably, the teachers in the coached and non-coached schools reported similar time spent in PD. These few studies represent a limited body of research on how literacy coaching influences teachers' knowledge of instructional strategies and how to incorporate them into their classrooms. In terms of disciplinary literacy, research focused on teacher knowledge of instructional strategies is especially limited. Teacher knowledge has been associated with either very specific strategies (e.g., save-the-last-word-for-me, a general reading strategy to get students discussing an important quote) (Edwards et al., 2011) or general knowledge of literacy development (Cantrell et al.,

2009) without a tie to the role literacy plays in their own subjects. Research that focuses on a specific literacy skill may provide more insights into how teacher knowledge of instructional strategies can be influenced by literacy coaching.

In addition to finding links between literacy coaching and knowledge of instructional strategies, research has also linked literacy coaching to changes in teachers' practices. Di Domenico et al. (2018) interviewed three high school social studies, math, and English language arts teachers after their experiences with a literacy coach. All three described at least one classroom example of using the strategies they developed with the literacy coach. These teachers also reported to having some ownership over these strategies because they were developed collaboratively as an exchange between the literacy coach and each teacher. Cantrell and Hughes (2008) likewise reported that 22 middle and high school teachers who taught English language arts, science, math, and social studies increased the frequency of literacy instruction after participating in workshops with ongoing coaching. This study combined teacher responses with observations, but the researchers conceded that the two observations they conducted with each teacher were insufficient to get a clear understanding of teacher implementation. They recommended more frequent observations of teachers' instruction, to determine their responses to literacy coaching, in future studies.

Characteristics of Effective Literacy Coaching

Research has indicated some elements of coaching models that may help address the challenges of secondary literacy coaching. In studies describing both successful or unsuccessful PD coaching, researchers have emphasized time to develop collaborative coaching relationships and responsiveness to individual teacher needs (including evolving coaching practices as teachers gain more experience). These elements reflect research on PD in general (Desimone, 2009; Reed, 2009), and also reflect more specific characteristics related to coaching. The following section elaborates on these two elements in more depth.

Time to Develop Collaborative Coaching Relationships

Teachers and coaches need time to develop collaborative relationships. Smith's (2012) multiple case study of three middle-school literacy coaches found that establishing and developing relationships with teachers was necessary to impact teaching practices. Coaches used questioning and critiquing of their own model teaching, rather than acting as the sole expert, to encourage teacher engagement without violating the relationships they had established. Calo et al. (2015) found similar results in a survey of 270 K-12 literacy coaches who reported that collaboration with teachers and developing good relationships were essential to their work as coaches. Newly recruited coaches reported that most of their time in their first year of coaching was building relationships with teachers (Ertimer et al., 2005). These studies bring up an important issue in literacy coaching as a PD model. Literacy coaching may not show immediate results, especially if coaches are working with too many teachers to effectively develop relationships and build collaborative teams. Additional research focusing on the way relationships influence coaching PD would help clarify how literacy coaching can be most effective.

Responsiveness to Individual Teacher Needs Over Time

Researchers (Ippolito, 2010; Strahan et al., 2010) have also noted the importance of responding to teachers and their needs. This includes acknowledging teacher strengths as well as weaknesses. Embedded in such a response are the changing needs of teachers and coaches over time. Collet (2012) conducted a case study over the course of 11 weeks with 46 teachers in a university laboratory working with three literacy coaches. The teachers were both inservice and preservice teachers completing literacy certifications for a master's degree and taught K-12 students. The literacy coaches kept a checklist of practices they mostly used to support teachers, which were triangulated with observations and artifacts. Over time, coaching practices changed from predominantly modeling effective practices or making recommendations, to affirming and collaborating with teachers. Collet argued that coaches should adapt their practices as teachers become more adept in literacy practices, distinguishing early stages of coaching from later stages, with the ability to adapt as needed.

Collet's (2012) case study confirmed other descriptions of coaching in middle schools over time where teachers declined offers of modeling in the second year of the PD (Feighan & Heeren, 2008). Another case study (Binkley et al., 2012) distinguished between coaching novice and experienced teachers; novice teachers asked coaches to model more often than more experienced teachers who used coaches to help plan and collaborate on ways to improve instruction. Teacher experience may be an important factor to consider in coaching models. Teachers may have different needs based on experience, or they may interact in different ways with the coach. Understanding teacher experience in the context of literacy coaching is essential in understanding how to support inservice teachers at all ranges of experience. More research is needed to understand how literacy coaching can be a responsive model of PD for teachers with a range of experience.

Summary of Research on Literacy Coaching

Research on literacy coaching in secondary schools has highlighted the complexity of PD in secondary schools (Reed, 2009). A variety of teacher, coach, and school characteristics influence the way teachers change their instructional practices: teacher backgrounds, literacy coach backgrounds, teacher beliefs about the role of literacy in the classroom, time to develop collaborative relationships, and the nature of those relationships. Research that ignores these components may give an incomplete picture of how literacy coaching may work at the secondary level.

The backgrounds of both literacy coaches and teachers need to be highlighted in future research. Coaching models are often represented as “static in nature, tending not to take into account how teachers’ needs and capacities change over time” (Collet, 2012, p. 32). Coaching models that account for differences among teacher backgrounds, including teacher experience and teacher knowledge of literacy practices, are important for guiding effective literacy coaching.

Literacy coaching in disciplinary contexts is largely missing from the literature in secondary schools. Much existing research describes literacy coaching as coaching for general (or content area) literacy instruction, but this type of coaching may further contribute to resistance from teachers who do not see relevance or value in these generic recommendations. Coaching for disciplinary literacy instruction may require distinct practices on the part of both teachers and coaches. In this case, coaches may not have the disciplinary expertise necessary to serve as an “expert,” but rather as a collaborative partner with the expert teacher (Wilder, 2014). Because students in secondary schools are asked to engage in more complex language and literacy practices of each discipline (Fang et al., 2014; Lemke 2004; Pearson et al., 2010), research should look at ways to disciplinary literacy coaching can potentially support high school teachers' literacy instruction.

Finally, the research on literacy coaching has not directly addressed complex disciplinary practices like scientific argumentation, even though argumentation has been identified as a core component of disciplinary literacy (Goldman et al., 2016). Disciplinary literacy coaching may help teachers develop the complex pedagogical skills necessary to supporting their students as they engage in quality argumentation such as reading information in multiple forms (charts, diagrams, etc.), critiquing and adjusting explanations, and using scientific terms to develop and share models and justify claims.

Argumentation in Science Education

Scientific argumentation in K-12 settings has gained increasing attention from researchers over the past three decades (Erduran et al., 2015; Faize et al., 2018; Jiménez-Aleixander & Erduran, 2007; Manz, 2015). Identified as a core scientific practice (Duschl & Osborne, 2002; NGSS, Lead States, 2013; Osborne et al., 2016), engaging in argumentation, both in oral or written forms, can immerse students in the epistemological and language practices of science (Ford, 2008a; Hand et al., 2003; Lemke, 1990; Ryu & Sandoval, 2012). As a discourse of science, scientific argumentation encapsulates ways of thinking and communicating that resonate with the disciplinary community, so I begin this section by discussing what counts as scientific argumentation and the key features researchers have ascribed to scientific research. While engaging students in a core practice of scientists may explain part of the growing interest in scientific argumentation, researchers have also examined the benefits of scientific argumentation on student learning including impacts on understanding scientific concepts. After defining scientific argumentation, I will examine the literature describing the benefits of argumentation on student learning before looking at the ways researchers describe scientific argumentation, including the necessary skills that help students engage in argumentation. I will then focus on research on instructional practices (how), the contexts of argumentation (when), and the purposes and goals of argumentation (why). I will conclude this section by discussing the research on teachers' experiences and beliefs about argumentation and science education and how PD can address both teachers' instructional practices and their beliefs.

Defining Scientific Argumentation

Argumentation in terms of academic discourse differs from common understandings of argumentation where arguments are often emotional or adversarial exchanges in which one side attempts to win or defeat the other side (Duschl & Osborne, 2002; Faize et al., 2018). In its simplest form, arguments have been described as an assertion or a claim that is supported or justified with evidence and/or reasoning (Sampson & Clark, 2008; Osborne et al., 2004). Duschl and Osborne (2002) defined arguments as "the substance of any meaningful discourse that seeks to generate *improved* knowledge and understanding" (p. 51). In developing his model of argumentation, Toulmin (1958) claimed that some features of argumentation are consistent across fields while others are "field-dependent" features of argumentation. For example, the type of data or warrants used by lawyers or judges may differ from those used in arguments of mathematics. Such disciplinary understanding of argumentation has been noted by multiple researchers who include argumentation as one epistemological practice of scientists where certain types of evidence and reasoning are prioritized over others (Ford, 2008a; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Walker et al., 2016).

In their review of research assessing students' scientific arguments, Sampson and Clark (2008) emphasized that "in order for arguments to be considered persuasive and convincing, they must be consistent with the epistemological criteria used by the larger scientific community for 'what counts" as valid and warranted scientific knowledge" (pp. 448-449). While discourse in any field is not static, in looking at the research several key features have been highlighted by researchers as key components of scientific argumentation.

The process of scientific argumentation has been described in two parts, one of construction or creation of an argument (Osborne et al., 2016) and one of critique (Ford, 2008a; Jiménez-Aleixandre & Erduran, 2007; Macpherson, 2016; Sampson et al., 2010). Constructing a scientific argument includes applying scientific knowledge to the problem (Faize et al., 2018; Osborne et al., 2016; Zohar & Nemet, 2002), making sense of evidence and data (Berland & Reiser, 2009; McNeill et al., 2016), and using reasoning to articulate and ultimately persuade the scientific community of the validity of the argument (Berland & Reiser, 2009; Faize et al., 2018). Additionally, critiquing and evaluating is a key component to argumentation (Ford, 2008a; Osborne & Patterson, 2011) which includes considering and evaluating multiple claims and explanations in addition to collaborating through discussion to refine and reconsider initial claims (Andriessen & Baker, 2014; McNeill et al., 2016; Osborne et al., 2016; Sengul et al., 2020; Sampson et al., 2010). Finally, while many argumentation activities have focused on arguments about socio-scientific topics (Cavagnetto, 2010; Dawson & Carson, 2020), or making claims describing a natural phenomenon (Macpherson, 2016), scientists also make arguments about the way evidence was gathered or the way the evidence is interpreted. As Duschl and Osborne (2002) claimed,

> Science requires the consideration of differing theoretical explanations for a given phenomenon, deliberation about methods for conducting experiments, and the evaluation of interpretations of data. Clearly then, argumentation is a genre of discourse central to doing science. (p. 52).

In sum, scientific argumentation is not merely an activity to add into the science classroom, but argumentation is a central component to all aspects of doing science.

Benefits of Argumentation in Science Courses

While scientific argumentation is one of the core scientific practices (NGSS, Lead States, 2013), it is a complex process that is often at odds with traditional forms of science education (Christodoulou & Osborne, 2014; Faize et al., 2018; Osborne, 2010; Osborne et al., 2014; Pimentel & McNeill, 2013). Beyond giving students opportunities to engage in authentic scientific practices, scientific argumentation has been linked to multiple benefits for students including improvements in students' conceptual understanding of science, scientific ways of thinking, and transferrable skills such as the ability to evaluate claims in areas other than science.

Research looking at conceptual understanding of science as a result of argumentation instruction indicates that argumentation can have positive benefits on student knowledge of science. Students who are able to discuss, critique, and question ideas may have a better long-term understanding of science (Osborne, 2010). Even short-term instruction of argumentation, as in the Venville and Dawson's (2010) study of tenth grade biology students, can lead to growth in science content knowledge. In their study, students showed significant improvement in their knowledge of genetics compared to students who did not participate in three argumentation lessons. Researchers (Mercer et al., 2004; Zohar & Nemet, 2002) studying younger participants reported similar results on science content knowledge. In two studies, collaborative argumentation, or activities in which students engaged in negotiating a solution as a group, led to improvement in science understanding as compared to individual argumentation (Sampson & Clark, 2009) and as compared to students in traditional classrooms with no collaborative talk (Mercer et al., 2004).

Argumentation instruction has also been connected to improving transferrable thinking skills such as reasoning, critical thinking, and knowledge of argument structures (Osborne, 2010). In conjunction with growth in content knowledge, several studies also found growth in reasoning skills (Mercer, et al., 2004; Venville & Dawson, 2010; Zohar & Nemet, 2002). Researchers (McNeill, 2011; McNeill & Pimentel, 2010; Namdar, 2017) found improvement in specific areas of argumentation such as specific evidence, explanations, or counterarguments in both preservice teachers and students. Ryu and Sandoval (2012), for example, described an elementary teacher who emphasized explicit justifications throughout the year. Students in this study increasingly used justifications in their own discussions and asked for specific evidence from others. After designing a classroom that supported argumentation, McNeill (2011) also found that elementary students had stronger arguments overall and improved in understanding explanation and evidence in science context. Even though researchers may have used different frameworks for evaluating reasoning and argumentation in their studies, collectively, a large body of work indicates the potential of argumentation instruction in improving skills associated with argumentation (Sampson & Clark, 2008).

Finally, teachers who focus on argumentation in science classrooms give students access to the language of science, allowing them to participate in science closer to the ways scientists participate (Cavagnetto, 2010; Lemke 1990). Students who participate in these scientific ways of knowing develop a better understanding of how we know science, not just what we know about science (Driver et al., 2000; Duschl, 2008).

Descriptions of Scientific Argumentation

Argumentation in K-12 settings can take a variety of forms. Researchers have used multiple frameworks to assess argumentation including generalized structures and domain-specific structures (Sampson & Clark, 2008). Argumentation may also be incorporated in the classroom as written arguments (McNeill, 2009), oral arguments (Christodoulou & Osborne, 2014), or as multi-modal arguments (Namdar, 2017). Additionally, because argumentation is a complex practice, researchers have focused on specific components of argumentation such as critiquing evidence (González-Howard & McNeill, 2020) or the types of claims being made (Macpherson, 2016). Below, I summarize the varied ways researchers have described scientific argumentation structurally, modally, and socially.

Structures of Arguments

The structural definition of argumentation refers to the components or elements that make up an argument (Sampson & Clark, 2008). Many researchers (Christodoulou & Osborne, 2014; Dawson & Carson, 2017; Dawson & Carson, 2020; Demİral & Çepnİ

(2018); Giri & Paily, 2020; Namdar, 2017; Oh, 2012; Simon et al., 2006) have used general structures such as Toulmin's (1958) Argument Pattern (TAP) including claim, data, reasoning, warrants, backing, qualifiers, and rebuttals as structural frameworks for argumentation. Other studies (Berland, 2011; Berland & Reiser, 2009; McNeill & Knight, 2013; McNeill & Knight, 2010; Sampson & Clark, 2009) have modified Toulmin's structural components by combining or omitting components. In both cases, TAP and a modified TAP has been used to support teachers' and students' understanding of argumentation and to assess the quality of their arguments.

To support students and teachers in understanding scientific argumentation, researchers have used TAP as the basis for PD and curriculum development in multiple studies. For example, Christodoulou and Osborne (2014) used TAP in the development of PD for a high school teacher's instruction of constructing and justifying scientific arguments. Similarly, Dawson and Carson (2020) used TAP in the development of curriculum for a high school science teacher. This curriculum supported the teacher in using multiple effective strategies for argumentation. After having students think about a problem and read and discuss the problem, Giri and Paily (2020) had students formulate an argument including a claim, data, warrant, qualifier, backing, and rebuttal before presenting their arguments using the TAP formula that led to increases in students' critical thinking.

Modified versions of TAP have also been used as tools to support an understanding of argumentation. McNeill et al. (2006) developed a scaffold to support students in writing scientific arguments that focused on claim, evidence, and reasoning (CER). McNeill (2009) provided this same scaffold to chemistry teachers in a study examining teacher instructional practices that support student argumentation. Subsequent studies (Berland, 2011; Berland & Reiser, 2011; McNeill & Pimentel 2010) have used the CER framework to develop curriculum in studies looking at teacher practices. Other researchers, such as Sampson and Clark (2009), modified TAP in a similar way. They created a framework that asked students to include an explanation which they equated to a claim in Toulmin's (1958) model, evidence, and reasoning in collaborative or independent conditions. In these studies, the structure of TAP primarily supported students in understanding that high-quality arguments should include certain components, such as claim, evidence, and reasoning.

TAP has also been used as an evaluative tool to assess the quality of scientific arguments such as in Dawson and Carson's (2017) study which evaluated students' written arguments about a climate change scenario using TAP. They found that students frequently made claims supported with data, but often omitted backing, qualifiers, and rebuttals. Similarly, Namdar (2017) used TAP to determine the presence and frequency of structural components such as claim, justification, rebuttal, and counterarguments in pre-service teachers' multi-modal arguments. The pre-service teachers in their study also included justifications more frequently and through more representations compared to rebuttals or counterclaims. In both of these studies, the primary focus was on the presence of argumentative components rather than the quality of each component.

Sampson and Clark (2008) also noted other structures that they described as domain-specific. In contrast to general structures like TAP that could be adapted to a variety of subjects beyond science, domain-specific frameworks "focus on aspects or criteria of argument specific to science or subfields and specific contexts within science"

(Sampson & Clark, 2008, p. 449-450). For example, Zohar and Nemet's (2002) framework included only two components: assertion and justification, but differentiated between weak arguments that include nonrelevant justifications and strong arguments that have multiple, relevant justifications. Similarly, Sandoval and Millwood (2005) developed a domain-specific framework that included claims and data as structural elements, but also evaluated the epistemological quality of arguments including the sufficiency of evidence, the coherence of the explanation, and appropriate rhetoric ("how students use data in their texts" (p. 32)). In these frameworks, the researchers attended to both the inclusion of important argument components as well as the quality of those components. Using domain-specific frames, arguments could be evaluated as low-quality even if they included all of the components.

Researchers have not treated the general structure of TAP and the domain-specific frameworks for argumentation as mutually exclusive. For example, Sampson and Clark (2009) used TAP as a framework for developing curriculum, but they assessed the students' arguments by scoring them on "(a) the sufficiency of the explanation, (b) the conceptual quality of the explanation, (c) the quality of the evidence, and (d) the adequacy of the reasoning" (p. 462). Even in domain-specific frameworks that prioritize the domain-specific evaluations of scientific argument, descriptions of scientific arguments have consistently incorporated two components: (a) something equivalent to a claim or assertion and (b) specific evidence and explanations in defense of that claim. (Zohar & Nemet, 2002; Sandoval & Millwood, 2005).

In looking at the structural components of arguments, many researchers (Berland, 2011; Berland & McNeill, 2012; Berland & Reiser, 2009; Cavagnetto, 2010; Osborne et al., 2016; Osborne & Patterson, 2011; Sandoval & Millwood, 2005) have addressed the overlap in terms of scientific argumentation and scientific explanation. Osborne et al. (2016) have noted that scientific explanations and arguments differ in their primary goal. They write, “The goal of explanation is understanding. In contrast, the goal of argumentation is persuasion” (p. 823). Furthermore, Osborne and Patterson (2011) argued, “Lacking a well-defined intellectual construct students are in danger of confusing the goals of argument and explanation, omitting vital elements of both” (p. 636). Other researchers have used the term scientific explanation rather than scientific argumentation to support teachers in addressing national standards that call for scientific explanations and to avoid the “negative everyday meanings around the term argument” (McNeill, 2009, p. 236). Berland and Reiser (2009) argued that the “often-implicit combination of argumentation and explanation and the overlap in their pedagogical goals suggests that it is often sensible to combine them into a single practice” (p. 28). Berland and McNeill (2012) have also argued,

> Although these scientific practices have different goals, they co-occur as individuals work together to build knowledge—scientists constructing explanations for a phenomenon argue about them using evidence and that argumentation enables scientists to improve upon their explanations. As such, we see the two practices of explanation and argumentation as having a complementary and synergistic relationship. (p. 809)

Other researchers (Berland, 2011; Goldman et al. 2016; Sandoval & Millwood, 2005) have noted that explanation is an important sub-skill that supports argumentation. Macpherson (2016), in comparing types of argument claims ecologists report making to the types of claims in existing research and curriculum for students, found that ecologists report making causal claims most frequently, but in the published literature students are asked to make more descriptive or prescriptive claims. Macpherson conjectured that this may be due to a distinction that researchers are making between explanation tasks and argument tasks. “The solution may be to simply add an argument component to an explanation task—for example, rather than only having to propose an explanatory model, students also have to defend their explanation and anticipate rebuttals” (p. 1085).

As a whole, the research on scientific argumentation agrees that an argument should include a statement, claim or position about a scientific topic with support for that claim. Beyond this consensus, scientific argumentation has used different methods of evaluation to determine the quality of arguments as well as differing definitions of what counts as argumentation.

Modes of Argumentation

Students and teachers also engage in argumentation through multiple modes. Some participants in scientific argumentation studies have been asked to engage in a single mode such as written argumentation (Berland, 2011; Sampson et al., 2010) or oral argumentation (Christodoulou & Osborne, 2014; McNeill & Pimentel, 2010; Simon, et al., 2006). In a few studies, researchers (Andriessen & Baker, 2014; McNeill et al., 2016; Namdar, 2017; Sampson et al., 2010) have combined multiple modes, having students engage in a combination of oral, written, and other modes (i.e., argument maps, graphs, and pictures). For example, Namdar (2017) had preservice teachers use multiple representations such as graphs, pictures, and texts to convey their arguments. To a lesser degree, other researchers (Sampson & Grooms, 2009; Sampson et al., 2010) have developed curriculum models that incorporate poster presentations in addition to written and oral arguments.

Many studies have focused on written modes of argumentation which range from completing shorter written tasks such as filling out a scaffold (Andriessen & Baker, 2014; Dawson & Carson, 2020; Sandoval & Millwood) to composing longer written responses (Cavlazoglu & Stuessy, 2018; McNeill, 2009; Sampson & Clark, 2009; Sandoval & Millwood, 2005). McNeill and Knight (2013) found that teachers were better able to provide feedback on written arguments after participating in PD but struggled critiquing oral arguments. Evaluation of student arguments using structural or domain-specific structures has often focused on students' written work (Dawson & Carson, 2017; Namdar, 2017; Sampson & Clark, 2008). Studies using quantitative or mixed methods looking at student improvement in argumentation have also tended to rely on written argumentation in these studies (Zohar & Nemet, 2002).

Studies dealing primarily with oral argumentation have looked at the ways teachers' moves have facilitated or inhibited whole group discussions. For example, McNeill and Pimentel (2010) emphasized the importance of open questioning in facilitating students' oral argumentation. Additionally, Mercer et al. (2004) emphasized collaborative oral discussions by supporting students with "explicit talk skills" (p. 363). Other research has examined teacher moves including how teachers frame the oral argumentations (Berland & Hammer, 2012; Pimentel & McNeill, 2013), how teachers evaluate and provide feedback on oral arguments (Christodoulou & Osborne, 2014; Erduran et al., 2006; McNeill & Knight, 2013), and how classroom environments influence oral argumentation (Berland, 2011). Overall, the research in oral argumentation notes the importance of moving teachers and students away from the traditional initiate, response, evaluate (IRE) model (Berland & Reiser, 2009; Pimentel & McNeill, 2013).

Additionally, many researchers (Ford, 2008b; González-Howard & McNeil, 2019; González-Howard & McNeil, 2020; Osborne, 2010) have emphasized the importance of developing student skills such as critique, in oral argumentation.

Current research on scientific argumentation has not looked at which modes have been most successful for teachers who are new to using argumentation in their classrooms. Research looking at which modes teachers are most likely to implement in their class may give insights about what PD models may support teachers best in incorporating argumentation into science instruction.

Social Groups for Argumentation

Researchers (Erduran et al., 2006; Ford, 2012; Giri & Paily, 2020; Kilinc et al., 2017; McNeill et al., 2016; McNeill & Pimentel, 2010; Sampson & Clark, 2008) have asked their students to engage in social forms of argumentation, "in which an individual tries to convince others either through talk or writing about the validity of a particular assertion" (McNeill, 2009, p. 235). Often referred to as collaborative forms of argumentation, social argumentation emphasizes persuasion of a specific audience as the main goal of an argument task. Collaborative arguments have been presented as an alternative to mainstream conceptions of argumentation as oppositional by focusing on reaching consensus rather than competing against each other (Andriessen & Baker, 2014; González-Howard, & McNeill, 2019). It is important to note that these types of social arguments present argumentation in conversation with another position.

The research suggests that argumentation in science classrooms can take many forms and combinations of forms. In looking at argumentation lessons, then, it is important to pay attention to the many ways teachers may be incorporating argumentation into their courses. The research on structural, modal, and social forms of argumentation has not looked at which types are of structures teachers who are new to argumentation are more willing to incorporate into their classroom. Research looking at which practices teachers choose to incorporate as they begin implementing argumentation can be beneficial to understanding where to start supporting teachers who have little experience with argumentation.

Instructional Practices, Contexts, and Purposes for Scientific Argumentation

In this section, I examine the research on effective instructional practices for scientific argumentation and the sub-skills students need. Additionally, scientific argumentation is one of many practices (Duschl, 2008; NGSS Lead States, 2013) that scientists engage in, so I look at the research discussing how scientific argumentation and the instructional practices to support it fit into the overall context of a biology class. Finally, as mentioned above, argumentation has multiple benefits for students including developing conceptual understandings of science (Mercer et al., 2004; Venville & Dawson, 2010; Zohar & Nemet, 2002), transfer skills (McNeill et al., 2011; Namdar, 2017), and scientific ways of thinking (Cavagnetto, 2010; Driver et al., 2000). To fully understand how teachers integrate argumentation into their classroom, it is important to understand their purposes for having students engage in scientific argumentation.

For example, researchers have focused on many sub-skills necessary for engaging in scientific argumentation. In some cases, teachers and researchers have focused on developing a sub-component of a skill instead of focusing on the entire argumentation process. For example, researchers have specifically targeted students' ability to critique others' positions in classroom discussions (González-Howard & McNeill, 2020.)

Additionally, researchers have also focused on some of the distinct skills students need to develop high quality argumentation such as reasoning, collaboration, and evaluation skills (Dawson & Carson, 2020; Kind & Osborne, 2017; McNeil, 2009; Osborne, 2010; Simon et al., 2006). Some of these skills are specific to certain modes of argumentation, such as oral language moves for oral arguments. Other skills, such as critiquing and evaluating, are essential for multiple modes of argumentation.

Effective Instructional Practices for Scientific Argumentation

Research into scientific argumentation has identified several patterns of effective instruction to support students in argumentation. In many studies (Berland & Reiser, 2009; Christodoulou & Osborne, 2014; Ford, 2008a; Ford, 2008b; McNeill, 2009; Osborne et al., 2013) instructional practices have been embedded in curriculum developed for teachers. For example, Berland and Reiser (2009) provided teachers with curriculum to examine the successes and challenges students have as they engage in scientific argumentation. Christodoulou and Osborne (2014) and Osborne et al. (2013) similarly used curriculum developed by Osborne et al. (2004) as PD in their studies. Additionally, some studies (McNeill & Pimentel, 2010; Ryu & Sandoval, 2012; Sampson & Clark, 2008) have examined how instructional practices have influenced student argumentation. For example, McNeill and Pimentel (2010) found that teachers using open-ended questions prompted students to "interact with their teacher and peers in terms of both building off and critiquing their ideas" (p. 206). Below I summarize the existing research on the effective instructional practices either as incorporated into studies as curriculum or examined directly.

Defining Argumentation. Defining the structural components of argumentation or explicitly directing students about the content of arguments has commonly appeared in multiple studies (Dawson & Carson, 2020; McNeill, 2009; McNeill et al., 2018; Simon et al., 2006) especially those relying on TAP or a modified TAP. Dawson and Carson (2020), using six categories of effective instructional practices identified by Simon et al. (2006), found that an early career science teacher frequently supported students' understanding of arguments by explicitly defining the structures of argumentation using TAP. McNeill (2009) also included explicit definitions of claim, evidence, and reasoning in the curriculum she provided to teachers. In comparing the way teachers instructed students, McNeill found that two teachers had changed the components of argumentation to make it less rigorous, namely substituting definitions of scientific terms for reasoning. In oral arguments, Mercer et al. (2004) found that providing explicit definitions of high-quality discussions supported students in developing their reasoning skills. Giri and Paily (2020) included direct instruction of the components of TAP in an argumentation intervention combined with other instructional strategies. They found that students participating in the intervention scored higher on critical thinking measures.

Scaffolding. Many researchers (Andriessen & Baker, 2014; Christodoulou & Osborne, 2014; Dawson & Carson, 2020; Giri & Paily, 2020; Sandoval & Millwood, 2005) have focused on the importance of scaffolding in supporting students' argumentation. Researchers have provided students with structural organizers to support them in developing their arguments (Dawson & Carson, 2020; Giri & Paily, 2020; Sampson & Clark, 2008). For example, Dawson and Carson (2020) provided students with multiple scaffolds including prompting students in oral arguments and providing students with writing frames based on TAP to support their written arguments. Similarly, Giri and Paily (2020) gave students a format for developing their written arguments using TAP and provided students with a TAP-based format for presenting their arguments orally to the class.

In facilitating oral argumentation, researchers (Christodoulou & Osborne, 2014; Erduran, 2006; González-Howard & McNeil, 2020; Kilinc, et al., 2017; McNeill & Pimentel, 2010; Mercer et al., 2004; Pimentel & McNeill, 2013; Ryu & Sandoval, 2012; Wang & Buck, 2016) have noted the importance of teachers in facilitating student argumentation by using scaffolds. McNeill and Pimentel (2010) examined three teachers and found that only one teacher helped her students engage in oral argumentation by asking open-ended questions. Kilinc and colleagues (2017), Christodoulou and Osborn (2014), and Wang and Buck (2016) also noted the importance of scaffolding discussions in studies where teachers failed to do so. For example, one pre-service teacher trying to facilitate oral argumentation was not able to facilitate the conversation and maintain classroom management (Kilinc et al., 2017). In two studies with elementary students, Mercer et al. (2004) and Ryu and Sandoval (2012) supported their students' oral argumentation skills by providing them with explicit oral language moves such as asking for justification (Ryu & Sandoval) and providing sentence starters to support reasoning (Mercer et al., 2004).

Scaffolds work to support students in argumentation by helping them understand the expectations associated with argumentation (Mercer et al., 2004). Scaffolds can also support teachers and students in transitioning out of traditional classroom practices that center the teacher in sense-making rather than the students (Pimentel & McNeill, 2013).

Context of Argumentation: When to Teach Argumentation

Few studies have directly examined when teachers use argumentation activities and how each argumentation activity relates to the instruction around it. McNeill and Knight (2013) noted the importance of PCK in teaching argumentation. They noted that PCK should account for how a teacher sets up a lesson and how they respond to learning difficulties. Such set-ups and responses imply that argumentation should be placed within the overall coursework strategically, but few studies have specifically mentioned ideal placement of argumentation. Cavagnetto (2010) coded scientific studies in his review as culminating activities. In this code, Cavagnetto implied the context of the argument activity as a culmination of a unit including both scientific background knowledge, investigation, etc. Additionally, other researchers (Sampson et al., 2010) have designed argument activities that are repeated multiple times throughout the year as lessons embedded within scientific units or as stand-alone lessons incorporated after instruction.

Several studies (Andriessen & Baker, 2014; Giri & Paily, 2020; Simon et al., 2006) have mentioned the importance of scaffolding and feedback. In some instances, the argumentation activity has been the completion of an argument using a scaffold (such as common computer scaffolds). In other cases, students have used the scaffolds to support smaller skills such as gathering evidence, or critiquing evidence before completing the argument task such as a written argument. Feedback implies that students are receiving feedback so that they can improve their skills, but it is not always clear how teachers or researchers build additional practices from that feedback. For example, several researchers have noted that teachers have struggled in giving feedback for oral arguments or accurately evaluating oral arguments. (McNeill and Knight, 2013; Christodoulou and

Osborne, 2014). There is no mention about how teachers and researchers expected students to use this feedback, (i.e., on a revision of the argument, on a subsequent argument practice).

Though researchers have looked at progressions of skills for students, looking at when argumentation is used in the context of other learning activities can be valuable in supporting teachers and students. One notable barrier to argumentation is the time argumentation activities take in a classroom. Understanding when argumentation activities are most supportive of student-learning, or understanding the times when teachers are most comfortable in using argumentation could support the strategic integration of this practice into the classroom.

Purposes for Argumentation

In a review of the research on argumentation in science, Cavagnetto (2010) found that argumentation has been used to support many different purposes including using scientific argumentation to support students in the language practices of science, the structure of arguments, and to teach science content. Henderson et al. (2018) wrote that learning goals influence the way that teachers implement argumentation instruction into their courses. Researchers (González-Howard & McNeil, 2019; Katsh-Singer et al., 2016; McNeill, 2009; Wang & Buck, 2016) have echoed that teacher goals for incorporating argumentation into the classroom impacted the way they framed the argument activity as well as how the students engaged in argumentation. Teachers' goals for teaching and learning, even unconscious ones, impact the ways teachers adapt new curriculum (Squire et al. 2003). Building on this idea specifically in argumentation, Berland (2011) found that the teachers' learning goals influenced the ways students engaged in oral argumentation.

Teacher Experiences and Beliefs About Scientific Argumentation

Researchers (Osborne, 2010) have pointed out the centrality of argumentation to the practice of science, but in elementary and secondary education settings, science curriculum has often omitted argumentative practices resulting in a mythical view of science as a series of facts rather than a critical evaluation of evidence (Lemke, 1990). As Duschl (2008) wrote,

> The dominant format in curriculum materials and pedagogical practices is to reveal, demonstrate, and reinforce via typically short investigations and lessons either (a) "what we know" as identified in textbooks or by the authority of the teacher or (b) the general process of science without any meaningful connections to relevant contexts or the development of conceptual knowledge. (p. 269)

Teachers' beliefs about the nature of science instruction, scientific argumentation, and the barriers and challenges in integrating argumentation play a role in the way teachers incorporate argumentation into their classrooms. I examine the research in each area below.

Experiences and Beliefs About Science Instruction

Teacher beliefs about the role of argumentation in science education may be tied to the instructional choices teachers make in the classroom (Zohar, 2007). First, teachers who view the goals of science education as covering a series of facts may view activities such as argumentation as taking time away from direct instruction (Pimentel & McNeill, 2013; Wang & Buck, 2016). Friedrichsen and Barnett (2016) examined this tension between science content and science practices with a group of biology teachers in a professional learning community. They found that many teachers reported struggling over the decision about which science skills and content details should be included in the biology curriculum. One teacher continued to struggle about whether the teachers were giving students enough science information. Other teachers explained that the emphasis on skills in *NGSS* was difficult for them because the teachers loved the content. The teachers' views of themselves as content experts required them to renegotiate their own identities to address new standards, and most of them did to a certain extent. Related to this view of content experts, researchers (McNeill, & Knight, 2013; Simon et al., 2006; Wang & Buck, 2016) have described teachers' worries that indirect instruction of science, especially instructional methods that ask students to examine why alternative views of science may be wrong, could confuse students and lead to inaccurate understandings of the facts of science.

Beliefs About Students

Additionally, teachers may see argumentation as more appropriate for high-achieving students, such as those in advanced courses. Several researchers (Osborne, et al., 2013; Pimentel & McNeil, 2013; Sampson & Blanchard, 2012) reported that secondary science teachers did not see argumentation as a skill all students should learn because they did not have the abilities to engage in higher order thinking skills. Teachers also acknowledged a lack of experience, claiming that students just want to be told the answers (Pimentel & McNeil, 2013). One teacher saw argumentation as a way to vary direct instruction but saw proficiency in argumentation as too difficult for some of his students (Wang & Buck, 2016). Beliefs about student ability are related to beliefs about the goals of science education. Teachers who see argumentation as too difficult for students may not see argumentation as central to understanding science (Osborne, 2010).

Experiences and Beliefs About Scientific Argumentation

In order for teachers to be able to instruct students in scientific arguments, they need to be able to create high quality arguments and be able to evaluate student arguments themselves (Cavlazoglu & Steussy, 2018; McNeill et al., 2016). Studies looking at preservice and inservice science teachers indicate that teachers may rely more on background knowledge rather than available data for support when constructing arguments (Sampson & Blanchard, 2012), or they may focus on claims and data without supporting explanations (Cavlazoglu & Steussy, 2018). Teachers without a complex understanding of scientific argumentation may reduce argumentation to "'algorithmic' approach that may result in superficial aspect of the program while neglecting its core" (Zohar, 2007, p.250), a practice McNeill et al. (2018) referred to as low fidelity to learning goals.

Scientific argumentation is a complex practice that incorporates disciplinary literacy skills including researching, gathering data, reading charts and graphs, evaluating alternative claims, and communicating positions in both written and oral formats (Goldman et al., 2016; McNeill et al., 2016). Secondary science teachers may have had little preparation in supporting science-specific literacy skills (Pearson et al., 2010; Snow et al., 2006). Researchers looking for ways to support teachers in incorporating argumentation strategies into their classrooms must also support teachers in incorporating the reading and writing necessary to fully engage in argumentation.

Teachers also need to know how to best support students in learning scientific argumentation. Pedagogical content knowledge (PCK) had been used as a framework to describe teacher knowledge of the ways to support students in argumentation skills (McNeill & Knight, 2013; Shulman, 1986; Zohar, 2007). Teachers not only need to have a complex understanding of argumentation but also a knowledge of how students learn, activities to support that learning, and pedagogical practices that facilitate skills such as dialogic discussion, making sense of data, evaluating claims, and developing counterclaims (McNeill & Knight, 2013; Simon et al., 2006).

Teachers need support in creating a classroom culture for argumentation (Henderson et al., 2018) including a classroom that allows for mistakes (Pimentel & McNeill, 2013), decenters teachers as the main authority in the classroom (Pearson et al., 2010; Zohar, 2007), and uses questioning to facilitate student-to-student discussion (McNeill & Pimentel, 2010). Secondary teachers have also expressed concerns about classroom management when utilizing argumentation. McNeill and Knight (2013) reported that high school teachers in their study expressed concerns about using oral argumentation in their classroom because they feared the students would start yelling at each other and the teacher would lose control. Osborne et al. (2013) similarly found that secondary teachers who participated in argumentation PD worried about classroom management and maintaining order in their classrooms. Even though classroom management might not be seen as directly related to PCK, teachers' worries may be more related to students disengaging from the learning goals (i.e., arguing for a scientific claim) and diverting to an off-topic task (i.e., winning an argument). Teachers who have the knowledge of the best ways to support student learning can ensure students stay engaged in developing argumentation skills and provide feedback for students as they practice these skills. PD models should address teacher concerns about new instructional strategies in order to help them develop knowledge in the best ways to support students in scientific argumentation.

Professional Development in Argumentation

Teachers in secondary science classrooms have traditionally taught science as a transmission of established facts in science (Driver et al., 2000; Duschl, 2008; Duschl & Osborne, 2002; Lemke, 1990). Teachers who have beliefs of science education as a transmission of science knowledge, rarely engage their students in scientific practices such as argumentation (Zohar, 2007). Litman and Greenleaf (2017) recently coded instruction of 34 exemplary teachers who were either known by the researchers or nominated by district leaders in multiple secondary disciplines. The science teachers they observed never used argumentation in their classrooms and relied on whole class talk for 99% of the observed instruction focused on fact acquisition and disciplinary knowledge. Other researchers (Duschl, 2008; McNeill & Knight, 2013; Osborne et al., 2004; Wang & Buck, 2016) have described argumentation PD as a complex and transformative practice because of teachers' reliance on lectures without providing students opportunities to engage in creating and developing scientific knowledge. Below I summarize the current research on PD to support teachers in scientific argumentation. I begin by discussing the impact of PD on teacher beliefs. Next, I describe the literature of PD related to teachers' understanding of scientific argumentation. Finally, I discuss PD and PCK for argumentation.

Professional Development and Teacher Beliefs

PD that reported positive changes to teacher beliefs about the nature of science education and student ability is both limited and mixed. Two studies (Erduran, 2006; Simon et al., 2006) found positive changes in teacher beliefs using collaborative models of PD. Erduran reported positive responses from preservice teachers and mentor teachers who collaborated on developing argumentation units. These middle-school teachers emphasized the importance of adaptability in creating and using the argumentation lessons after participating in the PD. Simon et al. also emphasized the teacher's role in creating and using argumentation units. Their PD for secondary teachers took place over the course of a year with six half-day workshops and three visits from the researchers to support teachers in introducing the lessons. The teachers in this study initially held beliefs that presenting alternative ideas to students would result in scientifically incorrect ideas, implying that these teachers saw science learning as absorbing information presented by the teacher. In the final workshop, however, the teachers recognized how argumentation was beneficial to students' science learning because it led to more engagement with scientific ideas.

In contrast to these studies, Kilinc et al. (2017) described the importance of positive teaching experience for lasting change. In their study, a preservice middle school teacher participated in an argument-based workshop focused on dialogic discussions. The teacher changed her view of science education from teacher centered to student-centered. During a practicum of teaching, however, the preservice teacher struggled to maintain control of the student discussion, felt challenged by students who questioned her content knowledge, and felt ineffective in her instruction. As a result of this negative experience, the preservice teacher reverted to her initial view that education should be teacher-centered. This case study provides an important example of what may happen as teachers implement unfamiliar instruction. Henderson et al. (2018) have noted that teachers will need multiple supports in terms of materials and feedback to help them develop these new, complex skills.

Simon et al. (2006) called for future research founded in teacher beliefs about argumentation in science. PD, as well as research surrounding the PD should account for worries about classroom management, the role of argumentation in the classroom, and teacher beliefs about the abilities of students. This study will address this call for research by developing responsive PD that acknowledges teacher beliefs and employs collaborative development of strategies for argumentation instruction.

Professional Development and Knowledge of Scientific Argumentation

Research focused on improving teachers in creating high quality science arguments have found that PD can support teacher knowledge. Cavlazoglu and Steussy (2018) provided a six-day workshop focused on improving ten high school teachers' scientific arguments. The workshop included concept mapping, collaborative game playing, and group lesson planning. In comparing arguments before and after the workshop, they found that teachers improved in the sophistication of their arguments in terms TAP. Another study about content knowledge of argumentation compared teacher science knowledge with critical thinking skills. Demİral and Çepnİ (2018) found that critical thinking skills were correlated to arguments that were more focused, open-minded, understanding of opposing ideas, and critical to holes in arguments. They concluded that critical thinking skills should be a central component to developing science teachers' understanding of scientific argumentation. These two limited examples of research in teachers' argumentation skills point to the need for PD that also supports teachers in understanding and developing quality arguments. Teachers who do not have a strong understanding of argumentation may reduce their instruction to superficial forms of argumentation where teachers may teach students the parts of an argument without engaging students in the practice of scientific argumentation, including evaluating the quality of claims (McNeill et al., 2016; Zohar, 2007).

Studies looking at teacher evaluation of arguments highlight a consistent challenge in teachers' understanding of argumentation. McNeill and Knight (2013) provided three PD sessions for elementary, middle, and high school teachers. This PD included helping teachers write models of arguments appropriate for the grade level of their students, evaluate students' work, and evaluate teacher instruction of argumentation. Teachers in this PD improved their evaluation of written argumentation, but they did not improve their evaluation of oral argumentation. The researchers recognized that the PD did focus more on evaluation of written work and called for more research helping teachers evaluate the quality of oral arguments. Erduran et al. (2006) examined preservice chemistry teachers who participated in six weeks of argumentation instruction. These teachers did incorporate argumentation into their instruction but demonstrated weakness in evaluating the quality of their students' work and providing feedback to improve the arguments the students created. Research into PD should incorporate disciplinary forms of scientific argumentation, including evaluating alternative claims and creating models of quality argumentation appropriate for the grade-level and subjects the teachers teach.

Professional Development and Pedagogical Content Knowledge

Studies have focused on increasing teachers' PCK, such as increasing the facilitation of dialogic discussions and components of argumentation structures (i.e. Toulmin, 1958). In each of these studies, teachers increased their use of at least one strategy supporting argumentation, while other strategies did not improve. Wang and Buck (2016) described an increase in one teacher's use of probing and open-ended questions after being given curriculum as PD, but he continued to direct the conversation and confirm or clarify a student's response. McNeill and Knight (2013) found an improvement in K-12 teachers' evaluation of teacher practices and student written arguments after participating in three PD sessions over the course of a year but noted teachers claimed they struggled in developing quality questions for student argumentation and instruction in oral argumentation continued to be a challenge. Osborne et al. (2013) described some teachers incorporating argumentation strategies such as supporting claims with evidence but found a wide variety in argumentation instruction. The mixed results in these studies point to the complex and long-term process of developing PCK in scientific argumentation (Osborne at al., 2013). McNeill and Knight noted that they provided unequal PD support in terms of written and oral argumentation, indicating the wide range of PCK that can be the focus of PD for scientific argumentation.

Other studies have pointed to disciplinary holes in PCK for argumentation, namely that teachers do not engage students in the process of critiquing and refining scientific arguments (Christodoulou & Osborne, 2014; McNeill et al., 2016). In summarizing their study, Christodoulou and Osborne provided recommendations for future PD to support knowledge of argumentation.

> PD programs should provide opportunities for the teachers to develop their own argument-based discursive actions, through providing feedback on the teachers'

> attempts to teach argumentation lessons, the types of prompts and questions they use during their lessons, and organizing workshops where the teachers are themselves participating in argument and counter-argument construction. That is, science teachers need to be introduced and trained not only into *teaching* science based on argument, but also *talking* science based on argument. (p. 1296-1297)

Given the limited research in the complex process of developing PCK for argumentation, more research is needed in understanding the ways teachers internalize and introduce instruction for disciplinary argumentation in their classrooms.

Summary of Research on Argumentation in Science

Using argumentation in science can lead to higher levels of thinking for students, improving both conceptual knowledge of science as well as reasoning and critical thinking. For these reasons, argumentation should have a central role in the science classroom (Driver et al., 2000). Yet argumentation is not a common practice in traditional science classrooms because argumentation often requires teachers to change their beliefs about teaching. Teachers need a strong foundation in creating supported arguments, so they can provide modeling for students and evaluate the quality of students' arguments. Additionally, teachers need to have strategies to support students in argumentation including facilitating discussion among students, defining and evaluating important features of arguments (e.g., claim, evidence, counterarguments), and developing high quality questions that will help students engage in argumentation.

More research in PD that supports teachers in scientific argumentation instruction is needed to examine the ways teacher beliefs about the role of argumentation, student ability, argumentation knowledge, and PCK influence how they integrate complex scientific practices. The complex components of changing teacher practice to include argumentation requires long-term, individualized support that allows teachers to become more comfortable with multiple strategies for argumentation. Research on PD for scientific argumentation indicates that collaborative work that allows teachers to participate in the creation of materials can influence teacher beliefs and practices about scientific argumentation. PD that includes opportunities for teachers to see models of practices, receive feedback on their instruction, and evaluate students' argumentation can support teachers' argumentation instruction.

Building on this literature, this multiple case study will use a year-long coaching model that responds to teachers' individual needs and provides ongoing collaboration among teachers to support their content knowledge and pedagogical knowledge of argumentation. PD in this study used a disciplinary coaching model to help teachers create exemplary models of arguments for tenth grade biology, co-create lessons for argumentation, and receive feedback and support from the disciplinary literacy coach to support teachers as they introduce new practices into their instruction.

CHAPTER III

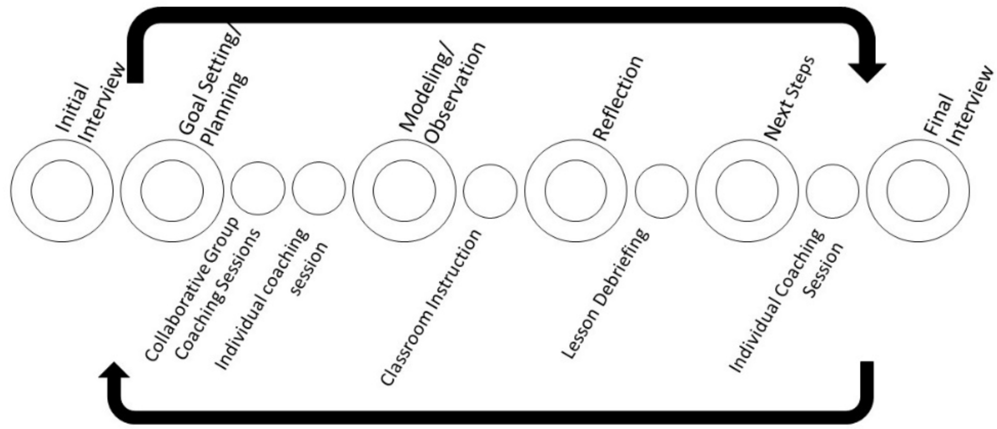
METHODS

Introduction

I used a multiple case study (Stake, 2006) of four teachers to examine the ways teachers incorporate argumentation instruction and how their experiences and beliefs mapped onto their instruction. Case study research allows researchers to look at a phenomenon "in depth and within its real-world context" (Yin, 2014, p. 16). Multiple case methodology is particularly suited for the ways teachers incorporate new practices into their courses because many factors facilitate and inhibit how teachers adapt and change their instruction. Additionally, in contrast to experimental designs which indicate whether a change has occurred, case study methodology can indicate how changes occur in relation to contextualized factors (Maxwell, 2004). These explanations can highlight the process of change, showing a link between instructional practices and changes in teachers' beliefs (Yin, 2014). A multiple case study also allows comparison among cases, offering multiple explanations that account for the differences in each case (Yin, 2014). In this multiple case study, I collected data from four biology teachers involved in disciplinary literacy coaching for three quarters to make sense of how teachers changed their instruction to include argumentation and the ways their beliefs about science and argumentation related to their instruction. Figure 1 provides a description of the coaching cycle teachers participated in during the study.

Figure 1

Description of Coaching Activities



Context of the Study

This study took place in a suburban high school in the western United States. This school was chosen because I had prior experience working with some teachers in the school both as a teacher and literacy coach. Because the literature on PD and literacy coaching indicates the importance of relationship building over multiple years, studying teachers in this school provided data in the context of a relationship that had developed over time. Additionally, because at the time of this study I was an insider in this school, my analysis of the patterns that emerged in this study provide an emic view that is different from that of an outside observer (Cochran-Smith & Lytle, 1990). Finally, this school was unique in the area because it wase the only secondary school in its district to allocate funds towards two part-time literacy coaches. One literacy coach worked exclusively with English language arts teachers. As the second literacy coach, I worked with teachers in other subjects to support their disciplinary literacy instruction.

The high school in this study had an enrollment of 1800 students at the time of the study, and 35% of those students were economically disadvantaged. The majority of the population were identified as Caucasian (74%) and 18% of the students were identified as

Hispanic on school records. Science teachers in this school frequently left within three years at the school. These frequent changes in science faculty as well as a general teacher shortage have led to teachers from alternate preparation programs to be hired to teach biology courses. In this school most students took biology in their tenth-grade year, so this course was the foundational science course for high school students. New teachers were often asked to engage students in higher levels of science (such as Advanced Placement) and to promote elective and advanced science courses for students in 11^{th} and 12^{th} grades.

Positionality of the Researcher

I was the disciplinary literacy coach in this study. As a participant observer in this study, I had an internal view of the case. “Such a perspective is invaluable in producing an accurate portrayal of a case study phenomenon” (Yin, 2014, p. 117). At the time of this study, I had taught English language arts and world history courses at this high school for 13 years. Five years prior to this, I developed the literacy coaching position in the high school with support and funding from the principal and worked as a disciplinary literacy coach with multiple content areas. This role took on many forms including presentations on literacy to the entire faculty, presentations to individual departments, collaborative disciplinary work with small groups of teachers, and one-on-one development of curriculum and team-teaching. In my work with science, math, family and consumer science, physical education, and drama, I have framed literacy as disciplinary practices in each of the disciplines.

In contrast to literacy coaching studies that often examine coaches who are new to a school, or who are in their first years of coaching, my role as a literacy coach built on existing relationships in addition to creating new relationships with biology teachers (Ertimer, 2005; Gross, 2010; Stevens, 2010). My participant role in this study gave me unique opportunities for additional data collection, such as impromptu discussions in between classes, collaborations during lunch, scheduling additional coaching sessions, quick meetings before or after school as needed, and other chances to interact with teachers as a coach. This advantage, however, potentially limited candid responses from teachers during interviews. This limitation will be addressed below.

Participants

Four biology teachers were asked to participate in this study as recommended by Stake (2006) because fewer than four cases limit the ability to draw rich comparisons, but four cases allow for a comparison of multiple differing cases while still being few enough to analyze multiple aspects of each case. All of these teachers reported having little to no experience of using argumentation in their courses prior to this study. Literature on literacy coaching (Calo et al., 2015; Ertimer et al., 2005; Smith, 2012;) identifies relationship building as a possible factor in the ways teachers engage with new pedagogical approaches. Because of this, I wanted to see how teachers who have already developed a relationship with the literacy coach differ from teachers who are developing a new relationship with the literacy coach. Thus, these participants were purposefully selected to exhibit maximal variation based on their relationships with me as a disciplinary literacy coach focused on literacy skills other than scientific argumentation. Two of the participants had some experience working with me as a literacy coach while the other two participants did not have any experience.

Additionally, research on literacy coaching (Binkley et al., 2012; Ippolito, 2010) indicates that the number of years teachers have taught could change the ways teachers engage with literacy coaches to facilitate new instruction, including openness to team-teaching and strategy modeling. I purposefully selected teachers with different levels of teaching experience and experience in the school to highlight possible differences in novice teachers compared to veteran teachers. One teacher for this study was a novice teacher (starting his 2^{nd} year). One teacher was a mid-range teacher (starting her 5^{th} year). Two teachers were veteran teachers (both taught more than 15 years). The characteristics of the teachers who participated in this study appear in Table 1

Table 1

Participant Characteristics

Teacher	Degrees	Years Taught	Subjects Taught	Description of Prior Experience with Coach
Julie	Bachelors in Molecular and Cell Biology Masters in Secondary Science	Four years	Biology Anatomy Earth Science	No experience
Jordan	Bachelors in Composite Biology Teaching Masters in Learning and Technology	18 years	AP Biology Genetics Chemistry	Collaborated on: • Developing close reading skills of genetic mutations texts, Coach modeled instruction. • Creating materials for debates about ethics in genetic testing of unborn babies. • Developing critical analysis of GMO articles. Coach modeled instruction. • Teaching close reading of multiple epigenetic texts. Coach modeled instruction.

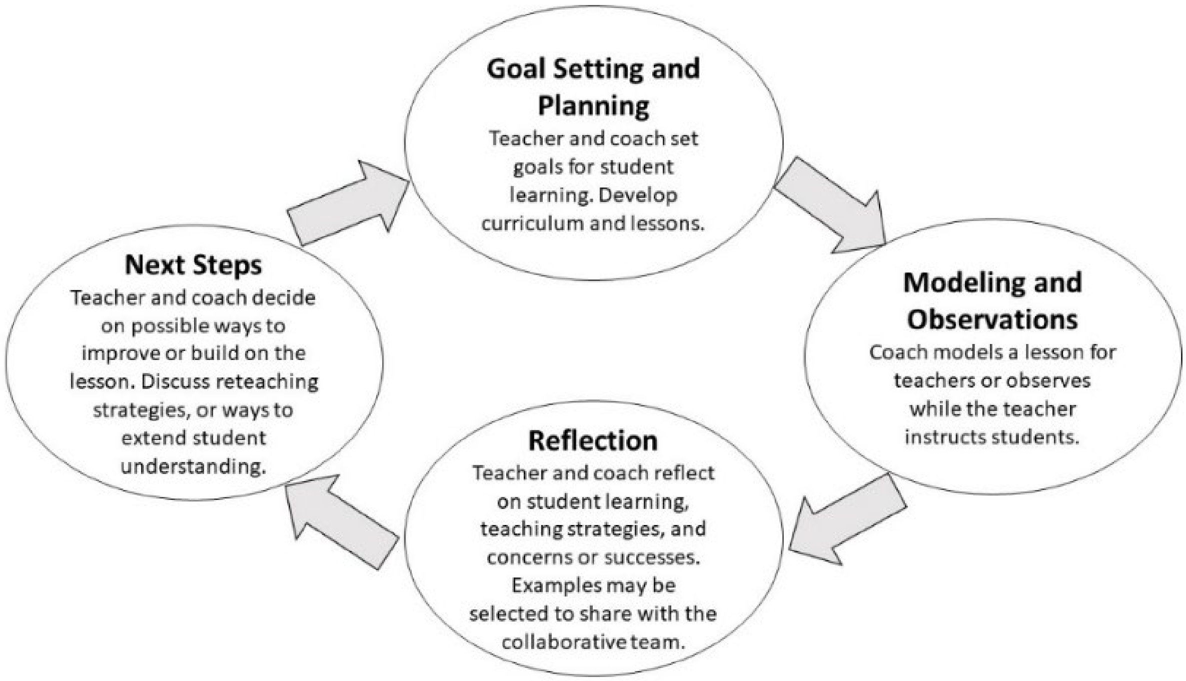
				• Coach provided feedback on reading materials and supports.
Mitch	Bachelors in biology Working on Masters in health science	One year	Biology Genetics	• Attended one faculty training on disciplinary literacy strategies
Andrew	Bachelors in ornamental horticulture Biology Teaching Endorsement	24 years	Biology Astronomy Plant science Greenhouse Aquaculture	• Attended 3 faculty trainings on disciplinary literacy strategies

Disciplinary Literacy Coaching for Scientific Argumentation

Professional development (PD) in this study was based on a collaborative coaching model in which the coach works with teachers in small group collaborations in conjunction with one-on-one collaborative coaching sessions. My background as an English language arts and social studies teacher made me a disciplinary outsider in biology (Di Domenico et al., 2018; Wilder, 2014). Collaborative coaching in this study cycled through goal setting and planning, observations and instructional modeling, debriefing sessions that provided opportunities for feedback and reflection, and discussions of next steps in terms of teacher instruction and student learning (Elish-Piper et al., 2016). Figure 2 shows the general cycle of literacy coaching that guided this study based on the Curriculum and Instruction standard for literacy coach preparation in the *Standards for the Preparation of Literacy Professionals, 2017* (ILA, 2018).

Figure 2

Coaching Cycle based on ILA Literacy Coaching Standards, 2017.



The disciplinary literacy coaching model in this study attempted to address research of effective literacy coaching as well as research on PD to support scientific argumentation instruction including substantial contact time (Desimone, 2009), responsiveness to teacher needs (Binkley et al., 2012; Henderson et al., 2018; Osborne et al., 2013), collaborative curriculum development (Darling-Hammond et al., 2009), and a content-specific focus (Garet et al., 2001). Some institutional barriers such as limited collaboration time and a soft closure related to COVID-19 limited the PD in this study.

PD Activities During Collaborative Group Coaching Sessions

Collaborative coaching sessions took place at the beginning of the study and once during the 2nd quarter of the year. The main focus of these sessions was to facilitate discussions about what high-quality argumentation looks like and to collaborate on questions and lessons teachers could use for argumentation. Working together, a group of four biology teachers and I examined and discussed science standards to identify science content where argumentation skills would support student learning. This activity emphasized collaborative PD that has been shown to influence teacher beliefs (Simon et al., 2006) and focus on standards-based content (Darling-Hammond et al., 2009). I also facilitated discussions about what scientific argumentation should look like. This activity was intended to elicit disciplinary knowledge of argumentation from teachers and identify areas in which teachers need support (Di Domenico et al., 2018; Osborne et al., 2013). Below is a list of specific topics we collaborated on in these coaching sessions.

- Defining scientific argumentation.
- Discussing socio-scientific argumentation and argumentation to explain a scientific phenomenon.
- Choosing a structure for teaching argumentation.
- Developing a question, lesson, and data source for scientific argumentation on climate change.
- Discussing student work on identifying and explaining evidence.

PD Activities During Individual Coaching Sessions

- I met with individual teachers to discuss the lesson(s) developed individually. This one-on-one coaching session allowed for teacher differences and provided responsive PD specific to the teacher’s needs (Binkley at al., 2012).

- The teacher and I collaborated on adjustments to materials as needed and discussed instructional strategies including open-ended questions, classroom management of student discussion, and assessments of student learning. In discussing instructional strategies, this activity was intended to support the teacher's PCK, and ease possible anxieties related to classroom management, student learning, or student ability (McNeill & Knight, 2013; Zohar, 2007).
- The teacher scheduled the time for the lesson and requested the coach to either model, team-teach, or observe. This activity addressed the different needs of each teacher in supporting instruction (Feighan & Heeran, 2008) and allowed me to adapt to possible changes in teacher needs over time (Binkley et al., 2012).
- After the lesson, the teacher and I debriefed the lesson as soon as we could. We discussed what worked and what did not work.
- The teachers and I looked over student work to co-assess and evaluate how students did on the lesson and skills we should focus on in the future. This activity was intended to build teacher knowledge of argumentation and provide support to teachers for providing feedback to students (McNeill & Knight, 2013).

PD Activities During Observations or Modeling

- The teacher and/or I taught the lesson. This activity was intended to provide job-embedded experience in a realistic setting (Darling-Hammond et al., 2009; Joyce & Showers, 2002).
- In the case that I taught the lesson, I also scheduled a time to observe the teacher using the lesson with a different class. This allowed the teacher and me to reflect

on differences in instruction, provide feedback to support PCK, and make plans for improvement in future lessons (Osborne, et al., 2013; Reed, 2009).

Substantial Time to Support Complex Instructional Changes. Research (Darling-Hammond et al., 2009; Desimone, 2009) in effective PD has highlighted time as a key characteristic in changing teacher practice. The number of contact hours for effective PD is not exact but ranges from 20 hours or more over the course of a semester (Desimone, 2009) to 30 hours spread over six months (Darling-Hammond et al., 2009). Studies looking at PD for scientific argumentation showed partial teacher change with 14 total contact hours over the course of a year (McNeill & Knight) or 24 hours total contact hours with additional observations over the course of a year (Simon et al., 2006). Osborne et al. (2013) attempted what they described as minimal PD which provided five days of PD over two years to teacher leaders who were expected to extend this PD to teachers in their schools in monthly meetings, but the researchers recognized these meetings varied from school to school as did the implementation of the lesson. Osborne and colleagues did not find significant changes to students' reasoning and concluded that PD specifically for scientific argumentation needed more contact hours with opportunities for instructional modeling and feedback.

As guided by research on effective PD for scientific argumentation, this study provided substantial contact hours in the form of individual coaching sessions (including reflective debriefing discussions), collaborative group coaching sessions, instructional modeling, and observations of teachers as they practice argumentation instruction. The exact duration of each of these sessions varied. Teachers received a stipend for participating in this study.

Responsiveness to Teacher Needs. Coaching studies (Binkley et al., 2012; Collet, 2012; Feighan & Heeran, 2008) have highlighted the differences in teacher needs as they engage in new teaching practices. Coaches in these studies responded to specific requests and adapted their PD support over time. Such responsiveness reflects research in effective PD, described by Desimone (2009) as active learning and as developing strong working relationships by Darling-Hammond et al. (2009). Such active learning may include observations of teachers as they try new instructional strategies, reflective discussion with an individual coach or with the group of biology teachers, modeling instructional strategies to the teacher's students, and group planning sessions. Research in PD for scientific argumentation (Henderson et al., 2018; Kilinc et al., 2017; Osborne et al., 2013) also suggests that teachers need ongoing and adaptive feedback to help them work through the challenges of introducing a new form of instruction.

In accordance with the research on responsive PD, the disciplinary literacy coaching model I used in this study provided flexibility for both the coach and teachers with built in opportunities for planning, instructional modeling, and feedback. In individual coaching sessions, teachers were able to request modeling of the instruction, team-teaching, or observation. By allowing teachers to adapt the support they needed and wanted, this component of the PD provided important information about how the teachers integrated new instruction within a disciplinary literacy coaching context.

Content-Specific Coaching Focus. Desimone (2009) claimed that PD focused on specific content was the most important characteristic of effective PD. Darling-Hammond et al. (2009) noted that PD should be directly related to state and district goals and provide support for lessons that teachers will use in their classrooms. Disciplinary literacy coaching provides a promising model for both of these areas because teachers drive the learning goals and content of the lessons while literacy coaches help elicit quality disciplinary practices and provide support to teachers in creating instructional strategies to teach these practices (Di Domenico, 2018; Wilder, 2014). This study took place at the same time the state introduced new science standards based on the *Next Generation Science Standards* (NGSS, Lead Sates, 2013). As the literacy coach, I centered discussions about scientific argumentation around these standards, which emphasize argumentation, and I encouraged teachers to adapt existing lessons where possible rather than introduce entirely new lessons into their instruction.

Data Collection

I used multiple sources to ensure quality in this study (Yin, 2014). I collected data from semi-structured interviews, individual coaching sessions, collaborative group coaching sessions, observations of instruction, artifacts from teacher instruction, field notes, and a researcher's journal. The data was collected from August until March to ensure that the data I collected was not related to an isolated event and to provide quality insights into teacher instruction (Yin, 2014). Table 2 provides an overview of data collected for this study. Each source of data is discussed in detail below.

Table 2

Overview of Data Collection by Research Question

Research Question	Source	Data Collection Procedure
How, when, and why do high school biology teachers integrate scientific	Classroom	• Audio recorded and transcribed observation of argumentation instruction

argumentation instruction in the context of disciplinary literacy coaching?		• Observation protocol • Artifacts of teacher instruction including handouts, graphic organizers, pictures of labs, etc.
	Biology Teachers	• Field notes and transcribed audio recordings of individual coaching sessions • Transcribed audio recordings of debriefing sessions • Audio recorded and transcribed collaborative group coaching sessions • Researcher journal • Reflections on instruction during semi-structured interviews
How do each teacher's experiences and beliefs map onto their decisions related to incorporating argumentation?	Biology Teachers	• Audio recorded and transcribed: • Semi-structured interviews • Audio recorded and transcribed collaborative group coaching sessions • Field notes • Researcher Journal
	Classroom	• Audio recorded and transcribed observation of argumentation instruction • Artifacts of teacher instruction including handouts, graphic organizers, pictures of labs, etc.

For this study, an important issue arose about the distinction between scientific explanations and scientific arguments. Many of the teachers viewed the ability to write scientific explanations as a foundational skill to developing scientific arguments. Their views echoed researchers like Berland and McNeill's (2012) claims that

> although these scientific practices have different goals, they co-occur as individuals work together to build knowledge—scientists constructing explanations for a phenomenon argue about them using evidence and that argumentation enables scientists to improve upon their explanations. (p. 809)

Though other researchers have argued for a clearer distinction between arguments and explanations (Osborne & Patterson, 2011) and NGSS (Lead States, 2013) distinguish between explanations and arguments as distinct practices, because the teachers saw explanations as a component of writing arguments and often used similar structures for both arguments and explanations, I included scientific explanations as part of the focus for this study. As Berland and McNeill also point out, many of the products of explanations and arguments "overlap significantly" (p. 809). To maintain consistency and avoid the often-difficult task of distinguishing argumentation from explanation, I refer to all practices that the teachers viewed as supporting argumentative skills as argument.

Similarly, teachers believed another distinct scientific practice, analyzing and interpreting data, was an essential skill for developing arguments. I also included lessons or activities where students were asked to analyze and interpret data as part of argumentation instruction when the teachers also saw these activities as a part of argumentation. Because the teachers and I discussed these lessons during and after coaching sessions, the intention of these data analysis activities in supporting student arguments was clear.

Semi-Structured and Open Interviews

Interviews provide important information allowing researchers to generate descriptions of participants' feelings, beliefs, and understandings of an experience (Roulston & Choi, 2018). Because of my role as the literacy coach, I used an external research assistant to interview the teachers two times: once at the beginning, and once at the end using a semi-structured interview protocol (Brinkmann, 2018). Semi-structured interviews provide more focus and structure than open ended interviews, but also allow the interviewer to pursue topics of importance. To guide these interviews, I developed questions prompting teachers to offer concrete descriptions focused on the topics of interest with possible follow up questions to prompt detailed and descriptive responses from the participants (Brinkmann, 2018). These interviews primarily address my second research question looking at teachers' beliefs and understandings. These interviews were used to confirm themes I noticed during observations and coaching sessions. Teachers were asked about topics I anticipated from existing research related to their teaching backgrounds: their beliefs about science instruction, argumentation, and student ability; their experience in learning and teaching argumentation; and their experiences with PD, including working with me as a literacy coach. Interviews were conducted by an external interviewer to reduce biased responses that may be related to my role as the literacy coach and my relationships with the teachers. I trained the external interviewer to understand the research questions of the study and trained the interviewer to ask follow-up questions and elicit additional details from teachers. Interviews were structured to take between 40 to 90 minutes.

Semi-structured interviews were conducted before the teacher began working with me as the literacy coach in August using the initial interview semi-structured protocol (see Appendix A). Throughout the study, I conducted open interviews asking teachers about unobserved argumentation instruction. These open interviews took place as part of individual coaching sessions debriefing teacher instruction and planning the next instruction. The final interview was conducted after the end of the school year in June using the concluding interview semi-structured protocol (see Appendix B). The final interviews were tailored to each individual teacher to elicit information I noted during observations, coaching sessions, and open interviews, missing information from the initial interview, and to acknowledge the teachers' unique situation (such as retiring, moving, etc.) Based on research of both literacy coaching and PD in scientific argumentation, the questions were categorized around topics such as teacher background, beliefs about science education and the teacher's role in science courses, content knowledge of scientific argumentation, PCK of scientific argumentation, and experiences in previous and current PD.

Table 3 shows the topics of interest in each semi-structured interview. In addressing the second research question, the on-going and concluding interview questions were used to ascertain how teachers' beliefs (e.g., teachers' beliefs about argumentation) connected with different instructional practices. Additionally, the protocol included questions directly related to the teachers' argumentation instruction during the study.

Table 3

Summary of Interview Topics

Interview Protocol	Topics of Interest	
		Ongoing Topics
Initial Interview	• General background and expertise in teaching science	• Perspectives of science education and the teacher's role • Content knowledge of scientific argumentation • PCK of scientific argumentation • Experience with PD (including coaching)
Open Interviews	• Discuss unobserved argumentation instruction • Evaluate student performance and discuss ways to move forward	
Concluding Interview	• Changes in views of instructional strategies or teaching practice	

- Responses to other topics that emerge from preliminary analysis of data

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Throughout the study, I was not able to observe all of the teachers’ lessons for argumentation. In some cases, this was because the argumentation lesson occurred spontaneously and informally. In other cases, the teacher decided to use argumentation in a lesson that was not planned with me as a literacy coach and forgot to schedule an observation with me. In these cases, I used open-ended interviews to discuss what teachers did, how they viewed their instruction, and what they planned on doing next.

Observations of Argumentation Instruction

During the second stage of the coaching cycle, (Modeling and Observation), teachers used the lessons they developed individually, with the coach, or with other biology teachers. Data from this stage in the cycle was collected by observing the teacher teach the lesson to one class. If the teacher requested modeling, I modeled the lesson during one class period and observed the teacher during a different class period, if possible. Because the lessons the teachers used in their classroom were developed in collaboration with me as a literacy coach or independently by the teacher, the length of observations for each teacher varied. I tried to observe lessons that I collaboratively developed with the teachers as well as other argumentation lessons the teachers developed on their own or with other biology teachers. I checked in with the teachers at the beginning of each quarter as well as periodically throughout the quarter to see when they had planned a lesson on argumentation. As noted above, in some cases, the teachers incorporated argumentation without letting me know, but they provided artifacts as well as an oral description of their activities during follow up coaching sessions.

I observed entire class periods (75 to 80 minutes) even if the argumentation lesson did not fill the class period to make sure I understood the context of the lessons. I developed an observation protocol to take notes during the observation based on Sampson et al.'s (2012)'s observation protocol for student argumentation (see Appendix D) and audio-recorded the lessons. All audio-recordings were transcribed and combined with the notes from the observation protocol to provide contextualizing information that may not have been captured on audio such as teachers writing on the board or affirming a student comment nonverbally. I reviewed all observation protocols and other notes prior to meeting with the teacher in a follow-up coaching session. For example, during one observation, I noted on the observation protocol that the teacher had changed the questions she had planned to use at the beginning of the class to prompt students to develop claims. I followed up with the teacher during our coaching session to discuss why she changed the question and how she felt the change helped or hindered her learning goals. I also used information from observations to add to the semi-structured interview protocols (see Appendices A-C).

Data from these observations were primarily used to answer the first research question. Observations provided information about when teachers used argumentation activities such as after instructing students about relevant content. Observations were also used to identify how teachers implemented argumentation, and finally, the observations provided insights into the teachers' purpose for using argumentation.

Observations in this study did not capture changes teachers made as they adapted each lesson over the course of multiple classes during the same day, since only one class was observed. To mediate this limitation, I relied on conversations during individual debriefing and planning sessions to gather information about any adaptations the teacher made during each iteration of the lesson. This is a limitation that is addressed later on.

Collaborative Group Coaching Session Observations

The biology teachers in this school were provided with time once a month to meet together with other science teachers in professional learning communities (PLCs). In the beginning of the study, I met with the biology teachers as a literacy coach to facilitate conversations about high quality scientific argumentation, discuss learning goals for students, and plan lessons for incorporating argumentation into their classrooms. Throughout the year, these planned PLC meetings were frequently replaced with faculty meetings, district meetings, and technology trainings. As a result, I was only able to facilitate three collaborative coaching sessions. The collaborative group coaching sessions that I facilitated were included as a data source in this study along with field notes from each session.

Individual Coaching Session Observations

The literacy coaching in this study primarily focused on individual coaching for each teacher. I recorded and transcribed formal individual coaching sessions with the teachers. Coaching sessions were also unplanned such as discussions during parent-teacher-conferences, discussions during lunch or while monitoring the halls together. For unplanned sessions, I took notes while we spoke, if possible, or quickly noted what we discussed as soon as I could document the conversation. These sessions provided information about the type of instruction teachers were planning, requests for material development from the coach, questions teachers had about their lessons, and the next steps in supporting students' argumentation ability.

Artifacts

I collected artifacts of lesson materials that teachers used in their classrooms including presentation slides, graphic organizers, journal questions, assignment instructions, etc. In the case that I was not able to observe an argumentation activity, I asked the teachers for all of the materials they used as I interviewed them about their lesson. I also collected all written interactions between the teacher and me such as emails, shared materials on Canvas, and other shared documents. I used these materials to triangulate themes I observed in observations and noted in interviews. I also used artifacts to supply the context of lessons that were unclear from the audio files of the lesson.

Collectively, the data sources described above provided me with a wide range of data in multiple contexts and over an extended period of time to ensure that I got an accurate understanding of the how, when, and why teachers incorporated scientific argumentation as well as the connection of their experiences, beliefs, and understandings to their pedagogical choices for argumentation.

Data Analysis

This study incorporated data from multiple contexts. This range of data from a variety of contexts allowed me to analyze data across contexts to triangulate the data and identify themes that emerged across the cases (Yin, 2014). I collected and stored my data on box.com as it was collected, sorting it into folders for each participant. Data sources were analyzed using the constant comparative method adapted by Boeije (2002). I started by open coding interviews and observations from each participant, comparing new codes to previous ones, and consolidating similar codes into categories and themes.

All initial interviews were transcribed by the second semester of the study. This allowed me to begin analysis, comparing teacher responses in each interview to data collected through observations and coaching sessions. I used this to guide my questions for the final interview, asking about experiences teachers had shared with me, asking about lessons teachers taught, and following up on any seeming contradictions in what the teachers said and what was observed.

Once all observations, interviews, debriefing sessions, and coaching sessions were transcribed, I read all the way through one teacher's data, marking and noting instructional practices (how) for argumentation, the context of the argument activity (when), and the teacher's purpose for argumentation (why) in different colors on the transcripts. For the second research question, I looked through the semi-structured interviews annotating for experiences, beliefs, and understandings. The interviews had been structured into these sections, but teachers also discussed their understandings and beliefs throughout the interviews. In reflection of the research literature, I had anticipated that teachers' understanding of argumentation, beliefs about science instruction, and experience with teaching argumentation would be important in understanding how teachers integrated argumentation into their classroom.

After looking at one teacher's full case, I went through the other teachers' interviews. As I read through each interview, I added additional categories that differed from the coding of the first teacher. I used constant comparative analysis (Glasser, 1965) to ensure that each code was consistent across cases. For example, I had noted that one teacher was providing feedback to his students using student models. In another teacher's observation, I had marked her practice of annotating all of her students' written work as feedback. I compared these two different instructional practices, noting how they matched (giving students information about the quality of their work) and how they differed (individualized feedback provided to the student versus helping students to notice the high and low qualities of a few key examples). As I compared teacher practices, I developed codebooks (see Tables 4-7) for each part of my first research question to help me define the themes and the sub-themes of how, when, and why teachers incorporated argumentation. As I noticed additional strategies in subsequent teachers' observations, I went back to observations I had already coded to see if these were present but overlooked. In some cases, as I noted additional themes, I noticed that a practice I had placed under one theme actually fit better with the new one. For example, I had viewed questioning as a scaffolding strategy for helping students think through argumentation. However, when I noticed that one teacher was using questioning as a way to help students identify the components of high-quality argumentation, I clarified two types of questioning depending on their purpose to define argumentation or scaffold argumentation. I continued to go back through each teacher's transcripts comparing sub-themes to the main themes in my codebooks.

To address my first research question, how the teachers incorporated argumentation into their classrooms, I first identified instruction intended to support students' argumentation in transcripts of observations, individual coaching sessions, observation protocols, and artifacts. In some cases, teachers used mini-lessons, or short lessons targeting a specific argumentation skill, before moving on to other activities. In this case, I coded only the parts of the lesson focused on argumentation. When teachers had multiple argument activities dealing with the same topic or question, I grouped these activities together as a unit. Each argumentation unit included all instruction related to the same idea or question. Because students can engage in scientific argumentation in multiple ways (e.g., oral or written, individually or collaboratively), one aspect of how teachers incorporated argumentation was the type of argumentation tasks teachers developed for their students. For example, some teachers designed written argument tasks relying on data from scientific texts. Another teacher designed an oral argument task in groups. I developed codes to describe the features of the argument tasks including style, mode, structure, duration, sources of data and reasoning, and class groupings. Table 4 summarizes the codes for the features of the argumentation units and provides examples of the codes. These features provide insight into how the teachers framed argumentation for students and how much variation they used in their argumentation units.

Table 4

How Teachers Incorporated Argumentation: Features of Argument Tasks

Category	Code	Example
Style: The informal or formal ways of engaging in argumentation.	Formal: The argument task was clearly defined with specific requirements, roles, and expectations.	*Explaining a classroom debate: "Each side is going to start with their opening speaker. Then you'll have a 3-minute recess to gather information to prove them wrong." (Mitch)*
	Informal: The argument task was less structured than formal	*So, first step at your table is to share your claim and a summary*

	activities. Students were not given specific requirements or roles. Expectations were more general such as minimal length requirements.	*of your supporting evidence. Then the other group members get to ask clarifying questions. After everyone has shared you can ask each other to challenge. (Julie)*
Mode: Written or oral argumentation	Oral: Students engaged in argumentation in small or whole group discussions.	*Talk at your tables: If you did edit DNA in a skin cell, where would that edit spread to? (Julie)*
	Written: Students engaged in argumentation through writing.	*Write an explanation answering this question: Are Viruses alive? (Julie)*
Structure: The format the teacher had the students use to develop and evaluate arguments.	CER: The students worked from the framework of claim, evidence, and reasoning as distinct components of the argument task.	*You need to have a claim, evidence, and reasoning—all three--- in every one of your explanations. (Julie)*
	CER + OV: The students were asked to incorporate at least one opposing view. Students addressed an alternate explanation, refuted an opposing opinion in socio-scientific argumentation	*How much red meet should people eat each week? Incorporate at least one alternate viewpoint in your response. (Julie)*
Duration: The amount of time the teacher and students engaged in argumentation.	Mini-Lesson: An argument task that took a portion of a class-period. Mini-lessons were smaller components of a larger unit or lesson goal.	*Look at these three examples of explanations. We're going to talk about these. (Jordan)*
	Single-Day: An argument task that was started and finished within a single class period.	*We're going to learn about argumentation today and you'll answer this question. (Mitch)*
	Multi-Day: An argument task that carried over several days of instruction. Multi-day argument tasks were not always consecutive days	*Remember that question I asked you two days ago? We're going to answer it again. Should be able to edit DNA? (Julie)*

Class Grouping: The way the teacher groups the students as they engage in argumentation.	Small group: The teacher asked students to engage in argumentation in small groups of 4 or less.	*Talk at your tables: If you did edit DNA in a skin cell, where would that edit spread to? (Julie)*
	Whole Class: The teacher asked students to engage in argumentation as a whole class	*Let me hear someone who thinks they have something good. You know what, student, why don't one of you two go? (Mitch)*
	Individual: The teacher asked students to independently engage in argumentation.	*I'm going to just do a little bit about how to write a thesis. You're going to get to get some individual writing time. (Julie)*
Source of Data/Reasoning: The sources teachers give or instruct students to use to develop their arguments.	Teacher Lecture: The teacher presented the information intended as evidence or reasoning for the argument task.	*As you listen to the information about evolution, fill in your chart with the important evidence you hear. (Andrew)*
	Scientific text: Students read scientific text including visual representations, charts, or models, to gather evidence and reasoning for their arguments	*Look at this chart. (Andrew)* *Read this article. (Mitch)*
	Investigation: Students plan and carry out an investigation to develop an argument. This includes deciding what to measure/observe, measuring/collecting data, and recording results (Duschl & Bybee, 2014).	*None. This code was included as one source of data key to scientific argumentation (Ford, 2012; Sampson et al., 2010).*
	Internet research: Students searched the internet for evidence or reasoning to support a claim	*Students researched information about privacy and genetics (Julie)*

To fully answer my first research question, I also looked at the specific instructional practices the teachers used to facilitate argumentation. I developed codes from transcripts of observations, observation protocols, and artifacts. Additionally, if teachers mentioned a specific practice they used in an interview or coaching session, I compared those statements to their observations and artifacts. Any practice the teacher mentioned in their interviews or coaching sessions that was not observed or apparent in artifacts was verified during member checking after the study and noted in the results.

The instructional practices codes described below in Table 5 explicitly focused on what teachers were doing to support students as they engaged in the argumentation units. For example, if teachers used oral argumentation, did they use open-ended questions to facilitate student to student discussion (McNeill & Pimentel, 2010)? After coding the transcripts for instructional practices, I categorized the codes based on the literature of scientific argumentation into three groups: direct instruction (Simon et al., 2006), feedback (Erduran et al., 2006; McNeill & Knight, 2013), and scaffolding (Dawson & Carson, 2020; Mercer et al., 2004; Ryu & Sandoval, 2012). These categories provided insight into how teachers developed student knowledge of argumentation and how they supported students during each argumentation unit.

Table 5

How Teachers Incorporated Argumentation: Instructional Practices

Category	Code	Example
Direct Instruction: The teacher provides direct instruction describing argumentation.	Argument terms: The teacher defined terminology of argumentation such as claim, reasons, or evidence OR the teacher reviewed previously defined terms.	*Um, what is evidence? What does that mean?* ***Student:*** *Support your claim* ***Teacher:*** *Support your claim, sure!* ***Student:*** *Stuff from the article?* ***Teacher:*** *Stuff from the article, yeah! So, is this just stuff that you make up?* ***Student:*** *It's like quotes* ***Student:*** *It's like facts!* ***Teacher:*** *Yeah, these are facts.* (*Jordan)*

	Science Specific Definitions: The teacher emphasized unique characteristics of scientific argumentation.	*And in science it's [evidence] usually something that's been observed. It's not somebody's opinion, right? Unless it's specifically about opinions. So, it's something that's pretty concrete and observable and fact-based. (Jordan)*
	Identification: The teacher identified or had students identify key components in existing arguments.	*Read this article. What's their evidence they use? And what was their reasoning for why this might be an issue? (Mitch)*
	Argumentation strategies: The teacher described ways to engage in argumentation such as critiquing sources, critiquing evidence, organizing their ideas, etc.	*Hey guys, don't forget. You can challenge the sources and you can look up the sources. So, if I say, "Hey, my source is Joe Schmo from this website," look up the statistics… If you don't think the statistics are valid or you think they're opinion based, you can call them out. (Mitch)*
	Inclusion Criteria: Gave students a list of what must be included in their arguments.	*Make a claim, list 3 pieces of evidence to support this claim, use reasoning to explain how the evidence supports your claim. (Jordan)*
Feedback: The teacher gives feedback on the quality of student arguments	Annotations: The teacher wrote comments on the students' assignments.	*Okay. Here are your papers back. I've marked them up. Yellow is evidence, pink is a claim, blue is reasoning. Look and see if you've got all three. (Julie)*
	Small group evaluation: The teacher directed students to evaluate arguments in small groups.	*Teacher prompted students to share their arguments with each other to see what other students included that they didn't. (Julie)*

	IRE Questions: The teacher used the IRE (initiate, reply, evaluate) questioning structure (Mehan 1979) to help students evaluate student arguments accurately.	***Teacher:*** *Did they answer the prompt?* ***Student:*** *Yeah?* ***Teacher:*** *Yes, they answered the prompt. They did, alright. Is there one right claim on this article?* ***Student:*** *No.* ***Teacher:*** *Yeah, no. That's kind of the nice thing about these, that there's no one right claim. Did they answer the prompt? That's what you've got to see. (Jordan)*
	Open questions: The teacher asked questions with multiple answers as students look at student arguments	*What do you notice about the evidence in this example? (Jordan)*
	Winner: The teacher indicated that a student or group created a better argument than an opposing student or group.	*Okay, so I'm tallying points. Security is winning right now. You have three minutes to prepare your defense. (Mitch)*
	Oral feedback: The teacher orally explained what was good or bad about a student's argument.	*K-- so maybe I'd add in evidence about greenhouse gases. So have greenhouse gases been going up or going down. And if you include that, I think that reasoning works. (Mitch)*
	Rubric: The teacher used a rubric to evaluate separate components of students' arguments such as the quality of the claim.	*Because I didn't have the rubric done until I was at the very end. And I think that would have helped. I think I had a hard time articulating what I wanted it to be. (Julie)*
Scaffolds: The teacher provides supports to guide students through argument tasks.	High-quality examples: The teacher provided students with examples of an argument to guide students in their own arguments.	*Teacher showed students an example of a high-quality thesis statement. (Julie)*
	Graphic Organizer: The teacher provided a graphic organizer to help students prepare for argumentation.	*Alright, so you see that sheet in front of you? It says claim, evidence, reasoning, and extend. (Mitch)*

	Questions: The teacher used questions as students engaged in argumentation to help them develop claims, reasons, or gather evidence.	*Teacher: Ok, so, what's your reasoning?* *Student: Because it sticks to your hand* *Teacher: What, you've got pigs sticking to your hand?* *Student: What?* *Teacher: What is it?* *Student: Water* *Teacher: Ok, so restate your reasoning.* *Student: The water sticks to your hand* *Teacher: Why? (Mitch)*
	Outline: The teacher provided an outline to help students organize their written arguments.	*I wrote an outline for them… So, I kind of gave them an outline as a scaffold. (Julie)*
	Notebook Entries: The teacher has students practice writing claims, answering questions, critiquing evidence, or gathering evidence in a scientific notebook.	*Put this table in your notebook: How could this factor possibly be impacting the climbing temperature?* *The evidence will come from the shape of the graph. (Julie)*

To address my second research question, I read through the initial interviews and highlighted and labeled the teachers' statements as experiences or beliefs. On a second pass, I developed categories reflective of the literature about teacher experiences and beliefs as well as categories that emerged from the transcripts. Table 6 defines the categories I developed to analyze teachers' experiences and beliefs. After identifying the category of each statement, I wrote a description of each teacher's experiences and beliefs for each category.

Table 6

Teachers' Experiences and Beliefs

Category	Codes and Definitions	Example
Teaching Experiences	**Student centered:** Teachers described their common instructional practices as requiring students to do the sense-making including independent, small group discussions, problem-based instruction, etc.	*I try to break it up into chunks and have them get up and move around… I'm like, you need to figure this out and I'm not going to tell you the answer. (Julie)*
	Teacher centered: Teachers described their common instructional practices as the teacher doing the sense-making and transmitting it to students through lectures, textbooks (Granger, et al., 2012)	***Interviewer:** What kind of instructional practices do you use most often in your biology classes?* ***Teacher:** Lecture, PowerPoint, worksheets. (Andrew)*
	Disciplinary literacy focused: Teachers described their common instructional practices as engaging students in reading, writing, and oral language practices central to scientific practices.	*I encourage reading, well writing's big… In fact, I had my students do that daily. So, for the first 20-30 minutes I would give my students a kind of current event type thing where they'd read… and I'd use that to guide into a lesson. (Mitch)*
	Scientific practices focused: Teachers described their common instructional practices as engaging their students in one or more of the scientific practices named in the Next Generation Science Standards (i.e., asking questions, developing models, investigations, analyzing/interpreting data, math, explanations, arguments, communicating info.) (NGSS Lead States, 2013).	*The content without the practices is kind of meaningless the same way the content without the practice is kind of meaningless…It's like, well like, there's only eight of them... So, every eighth day, ish? Like, they should always be there at some level. (Julie)*
	State testing focused: Teachers described their common instructional practices as test preparation for an end-of-level exam required by their state including administering practice exams and reviewing content for tests.	*Up until two years ago, we always had a year-end test. End-of-level test, SAGE test. And everything that wasn't tested on the test, I didn't teach. (Andrew)*
Argumentation Experience	**Student Experience:** Teachers described their experiences with argumentation as students in science courses.	*I had to write research papers and present information. That's not really argumentation. It's not two different sides of the same idea. No. So, I haven't*

		done very much of it at all. (Andrew)
	Teaching Experience: Teachers described their experiences with teaching argumentation to their students.	***Interviewer:*** *Okay, great. Um, and then, how often do you use argumentation in your classes?* ***Teacher****: Not often…* ***Teacher:*** *It means not at all. (Mitch)*
	Personal Experience: Teachers described their experience with scientific argumentation beyond the school setting such as reading scientific arguments.	*I'll read like argumentative materials on like, hey, is this the best? Like, I love genetics. Is this, is DNA manipulation, is this the best way versus this? I have like my little Science Daily clips that I'll go to and geek out. (Mitch)*
Beliefs about Science Education	**Purpose of Biology:** Teachers described the beliefs about the learning objectives and expectations for students.	*They have to learn the curriculum. We have five main topics: Ecosystem, chemistry of living cells, genetics, evolution, and organs and organ systems. So, these are what we'll be talking about. (Andrew)*
	Instruction: Teachers described their beliefs about the best instructional practices for students in a biology course.	*So ideally you don't tell them any fact you have them discover them themselves and hopefully they come to the right conclusion. So, I guess as much as you can do that it is a good thing it is. (Jordan)*
	Challenges: Teachers described their beliefs about the challenges in helping students achieve their learning goals.	*I have noticed since I got here. they I used to try and do more fun activities with those kids and these guys are just like give me the easiest path from here to here. And if you want to make them do something they struggle with it.* **(***Jordan)*
Beliefs about	**High Quality Scientific Argumentation:** Teachers described	*Arguments have a claim, evidence to support that claim,*

Scientific Argumentation	their beliefs about what makes a high-quality argument.	*and reasoning that link the evidence to that claim. (Jordan)*
	Value: Teachers described their beliefs about the value of incorporating scientific argumentation in their classroom.	*And negativity generally, even in the best managed situation, is a product, one of the primary products or arguing. (Mitch)*
	Challenges and Barriers: Teachers described their beliefs about challenges and barriers to teaching argumentation to students.	*Kids really struggle what counts as reasoning. Like, I have a claim and I have a piece of evidence. And, like, how are those two things connected? Telling me the moon is made of cheese because Peyton Manning's passing rate is XYZ is not useful. So, reasoning is hard. (Julie)*
	Personal Ability: Teachers described their beliefs about their ability to incorporate argumentation effectively into their classes.	*I think it's [argumentation] really good for AP, so I just need to do a better job of it… I wasn't good enough at it. (Jordan)*

After describing each of the experiences and beliefs of each teacher, I looked for patterns of how their experiences and beliefs related to their incorporation of argumentation. I concluded my analysis by looking for themes across the four cases in a cross-case analysis.

Trustworthiness

I collected data from multiple sources to allow for triangulation of the data. (Yin, 2014). As I worked through the analysis process, I also used peer debriefing with two experienced qualitative researchers with expertise in literacy instruction. Peer debriefing or review is "the review of the data and research process by someone who is familiar with the research or the phenomenon being explored" (Creswell & Miller, 2000, p. 129). We discussed the definitions of the themes as well as the examples I provided of each theme. With any disagreement or confusion, we talked about how each code fit into each research question, which codes were irrelevant to research questions, and which codes needed to be clarified, combined, or revised.

Finally, I used member checking (see Appendix D) to ensure validity of my findings. Member checking is an essential process in ensuring validity in qualitative research because it allows the participants to play a role in validating the findings (Creswell & Miller, 2000). After analyzing the data, I created a handout for each participant detailing the themes related to how, when, and why teachers incorporated argumentation. I also created a handout summarizing the experiences and beliefs for each participant. I provided the handout to the participant and discussed the evidence I had seen for each theme. Participants were asked if the themes made sense, were accurate, and were accurately connected to the evidence from the observations and interviews. I took notes on teacher responses and adjusted each case as needed.

Limitations

One limitation to this study is my role as a literacy coach at the school. My reputation as a coach and my relationship with each participant may have affected the types of responses teachers provide in interviews and coaching sessions. Though I tried to limit this possible bias by relying on an external interviewer to conduct the interviews, and I triangulated the data to make sure it was validated, teachers may still have adapted their answers because of their relationship with me. This limitation should be considered in using the results of this case study.

Another limitation relates to collecting data through observations. I only identified one class (e.g., first period) to observe as the teacher incorporated instruction for practical reasons. However, all of the teachers taught the same subject more than once and may have changed their instruction in different iterations. I tried to mediate this by prompting teachers to discuss other ways they taught the lesson during coaching meetings, but time limitations did not always make this possible. Even though I did not observe every practice in argumentation, the long-term nature of this study (over the course three quarters) provided me with observations of the teachers multiple times in multiple contexts and helped me form valuable and reliable conclusions from the combined data collection.

The observations of instruction and coaching sessions with teachers were centered around argumentation. Because I was not working with all of the teachers on all of their units, the data collection was limited to what the teachers' saw as argumentation. In some cases, teachers may have engaged students in ways that supported their ability to create arguments such as developing skills in analyzing evidence, informal oral arguments about the validity of scientific explanations, or socio-scientific arguments. When a teacher did not see these activities as fitting into their understanding of scientific arguments, they did not discuss these activities with me. Because teachers' views of scientific argumentation differed, teachers with a narrow view of argumentation were observed less frequently and activities that may have been observed for one teacher may have been omitted for others. This study should be interpreted with this important limitation in mind.

The collaboration among teachers with me facilitating as a literacy coach was another limitation to this study. Though PLCs were planned throughout the year, many of these meetings were changed to technology trainings or faculty meetings. Some PLCs were planned, but teachers were unable to attend due to conferences, athletic obligations, or other required meetings. The collaborative component of this study was limited because of these issues, though individual collaboration between the coach and teacher were conducted as planned.

Finally, this study was intended to extend a full year, but was cut short because of soft-closures due to COVID-19. All of the teachers had at least one additional argumentation activity planned for the final quarter of the year, but no teachers used that activity when they went to online learning. In two cases, the main argumentation activity that would synthesize the argumentation skills students had practiced over the course of the year was never incorporated into the lesson. In spite of this limitation, all teachers were still observed multiple times and each teacher participated in multiple coaching sessions to support their instruction.

Chapter IV

Results

Introduction

The goal of this multiple case study was to understand the ways high school biology teachers integrate argumentation into their instruction in the context of literacy coaching. I specifically wanted to know a) how, when, and why teachers integrated argumentation into their course? and b) how their experiences and beliefs mapped onto their decisions related to integrating argumentation? Below I report the findings of each case for both research questions. I begin with the teacher who integrated argumentation most frequently into her instruction, followed by teachers who integrated argumentation less frequently. After describing each case individually, the final section of this chapter is a cross-case analysis, highlighting patterns and distinctions among the cases.

Case 1: Julie

At the start of this study, Julie was a new teacher to this high school. She had previously taught for four years. Three of those years were in another state where she taught mostly biology and an elective anatomy course. Her previous year of teaching before this study was in a nearby junior high school where she taught earth science to ninth graders. Before teaching, Julie had worked as a research assistant for a PhD student in Panama. Julie was highly involved in the science education community which included attending and presenting at science education conferences.

During the first collaborative coaching meeting with all four biology teachers, Julie was the only teacher who reported having some experience in scientific argumentation. In spite of being a new teacher to the school, she was the most vocal about how she thought they should use scientific argumentation. Julie created most of her own curriculum for the argumentation units she incorporated, sharing many of her text sets and graphic organizers with other teachers. She needed little prompting from me as the literacy coach to begin to self-evaluate her own instruction or to begin planning ways to improve her instruction. Julie worked the most collaboratively with me as a literacy coach. We worked together to develop feedback, scaffolds, and data sources for her argumentation activities.

Below, I first focus on how Julie integrated argumentation into her instruction including the types of argumentation units and instructional practices she used (how), when she incorporated the practices into her instruction, and her learning goals and purposes for the argumentation units (why). Next, I address my second research question, looking at how Julie's experiences and beliefs mapped onto her decisions about argumentation instruction. I specifically describe Julie's experiences in teaching and argumentation as well as her beliefs about science education and scientific argumentation. Julie's beliefs about argumentation became more nuanced and developed by end of the study, so I conclude Julie's case with a description of her beliefs after incorporating argumentation into her class.

Julie's Integration of Scientific Argumentation: How, When, and Why

The intention of my first research question was to look at the ways each teacher incorporated argumentation into their class. I developed codes to describe the instructional strategies the teachers used to engage students in argumentation, in other words, how the teacher integrated argumentation. The first section below looks at the design of each of the argument tasks such as how argumentation was defined for the students as well as other key features like the duration of the activity, the class groupings, and the type of data students were using for evidence. These results came from the transcripts of the observations, coaching sessions, and artifacts. The second section describes Julie's specific instructional practices, when she used the practices, and why she used them.

Overview of Julie's Instruction and Design of Argument Tasks

Julie consistently incorporated argumentation activities into each academic quarter. When the tasks Julie gave to her students to teach argumentation aligned to the same topic or the same question, I grouped those tasks together into a unit. In some cases, these units also incorporated other instructional practices aside from argumentation. She had students complete six argumentation units, with some units including multiple activities throughout the unit. Each of the units describe the argument structure (Claim-Evidence-Reasoning (CER) or CER + counterclaim (CC)), the style (i.e., formal or informal), the mode (i.e., written or oral), the duration, the data sources, and the class groupings. A summary of each unit appears in Table 7. The units are labeled by the common question or topic for the argumentation activities.

Table 7

Case 1: Features of Julie's Argumentation Units

Units	Structure	Style	Mode	Duration	Source of Data/ Reasoning	Class Grouping
Is a Virus Alive?	CER	Formal	Written	Single Day	Scientific Text	Individual
Predator and Prey Regulation	CER	Formal Informal	Written	Multi-Day (2)	Teacher Lecture Scientific Text	Individual Small-Group
Human Impact on Climate Change	CER	Informal Formal	Written	Single-Day	Teacher Lecture Scientific Text	Individual Small-Group
How Much Red Meat Should You Eat?	CER + CC	Informal Formal	Oral Written	Single-Day	Scientific Text	Individual Small-Group
Which treatment is most effective for cancer?	CER+CC	Informal	Oral Written	Single-Day	Teacher Lecture Internet Search	Small-Group Individual
Should We Edit DNA?	CER Essay*	Informal Formal	Oral Written	Multi-Day (8)	Teacher Lecture Scientific Text	Individual Small-Group Whole Group

* See Appendix E for a description of the essay

Julie introduced a general argument structure, CER, to her students during the first quarter, emphasizing how to identify and write claims, and differentiating evidence from reasoning. In the second and third quarters, Julie added in what she called the counterclaim to the CER structure (CER+CC). She asked students to address alternate claims including evidence and reasoning for the counterclaim. Students were then directed to explain why their own claim offered a better explanation than the alternatives. In the last quarter of the study, Julie anchored her whole unit around argumentation. As she and her students proceeded through the unit, Julie used informal journal entries, whole classroom discussions, and small-group discussions to help students develop and adapt their claims as they gathered more information. She finished the unit by having students develop an argumentative essay incorporating elements of the CER structure into a broader template. Appendix E includes the content requirements for the essay as well as a template to support students' organization of the essay.

Julie most frequently required students to develop formal, written arguments (arguments with clear requirements for format, content, and organization) individually. She also relied on small-group discussions to support students in generating ideas for their individual arguments or in evaluating the quality of their arguments. Julie did not use any formal oral argumentation but used oral discussions to support students' argumentation skills informally (impromptu arguments without clear requirements for format, content, or organization).

In addition to focusing predominantly on formal, written arguments, Julie also relied mostly on scientific texts such as scientific articles, graphs, charts or diagrams as well as teacher lectures as the source of the data and reasoning for students' arguments. Notably missing in the sources are data from investigations conducted by the students such as conducting experiments or gathering data from observations.

Julie's Instructional Practices for Scientific Argumentation

Julie used a variety of instructional practices to support her students in scientific argumentation. Each of Julie's units began with direct instruction or a review of the argument structure for the unit and included some type of scaffold and some form of feedback. Table 8 shows the instructional practices incorporated into each of Julie's argumentation units. When the instructional strategy was used multiple times in the unit, the number in parenthesis depicts the frequency for that unit.

Table 8

Case 1: Julie's Instructional Practices by Unit

Units	Direct Instruction	Scaffolds	Feedback
Is a Virus Alive?	Defined CER	Graphic Organizer Questions Notebook Entry	Annotations
Predator and Prey Regulation	Reviewed CER	Graphic Organizer	Annotations Small Group Eval.
Human Impact on Climate Change	Identified Evidence and reasoning	Notebook Entry Graphic Organizer	Annotations
How Much Red Meat Should You Eat?	Reviewed CER Defined Counterclaim	Notebook Entry	Annotations
Which treatment is most effective for cancer?	Reviewed CER Identified Evidence and reasoning Listed Inclusion Criteria		
Should We Edit DNA?	Defined Thesis Defined Scientific Reasoning vs. Ethical Reasoning Described critiquing ideas	Notebook Entries (2 days) Graphic Organizer Questioning (4 days) Small Group Disc. (2 Days) Whole Group Debate High Quality Model	Oral Feedback Rubric

Direct Instruction. Julie consistently used direct instruction in all of her units specifically to teach the structure of argumentation that she wanted students to use. As Table 8 shows, this direct instruction centered around defining the components of argumentation that Julie saw as effective argumentation. Specifically, she defined claim, evidence, and reasoning for the students.

Julies' direct instruction for each argumentation unit occurred at the beginning of each unit with the exception of her unit, "Should we edit DNA." In the other five units, Julie started each unit by defining the terms of argumentation and emphasizing that scientific arguments must include all components. Julie noted in her final interview that she spent the most time using direct instruction in the first argumentation units and less time in the subsequent lessons. "At the beginning of the year, there's some explicit instruction. Like this is how you write. I put up a slide, and I'm like… 'An argument must have a claim, evidence, reasoning, and a counter argument."

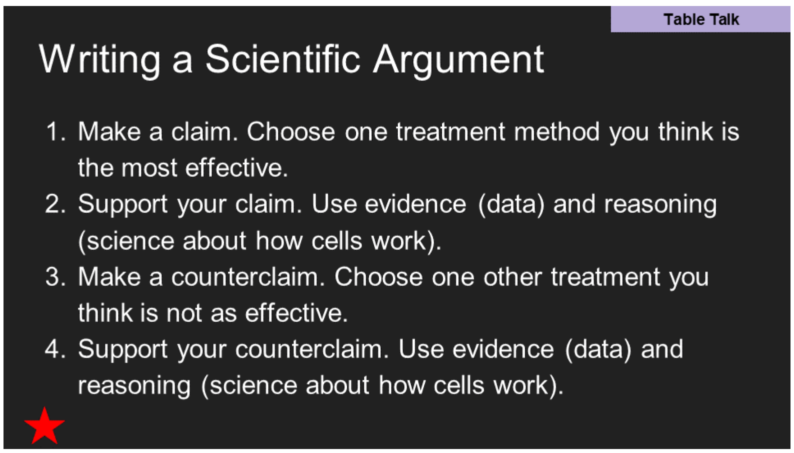
In two of the units, Julie also used direct instruction to help students distinguish between evidence and reasoning. In the unit "Human Impact on Climate Change," Julie provided students with a series of graphs showing the impact of different factors on the earth's temperature. She directed the students to gather evidence and reasoning from the graphs into a table, telling them, "The evidence will come from the shape of the graph and the theory will come from the text below the graph." In another unit, Julie had students read a text set about how red meat impacts human health. Julie helped the students identify the author's claim, evidence, and reasoning in each article before developing their own claims about the impact of red meat on human health. In both of these units, Julie's purpose was to develop students' understandings the components high-quality argumentation. With this type of explicit instruction, Julie helped students identify examples of the defined terms in published scientific arguments rather than simply providing them with a definition. This direct instruction, like the definitions of the terms, occurred before students were asked to create their own arguments on the same topic.

The one unit that did not begin with direct instruction of argumentation was the final unit, "Should We Edit DNA." In this unit, Julie directly instructed students about the thesis or scientific reasoning towards the end of the unit, when students were beginning to write their argumentative essay. This unit differed from the others because the argument activities during the unit tended to be informal and served to help students revise their ideas about editing DNA rather than have them write formal arguments throughout the unit. At the end of the unit, after students had been given multiple opportunities to discuss, informally write, and revise their ideas, Julie assigned students an argumentative essay. Before students began their essays, Julie provided direct instruction about what should be included, new terms such as thesis statements, and distinctions between ethical and scientific reasoning.

Julie's direct instruction focused on defining what should be included in high quality arguments. Julie did not discuss the quality of each of these components, but she emphasized what they were and where they should be used in arguments. Figure 3, for example, shows a Google Slide Julie used before students worked in groups to develop a claim about the best treatment for a newly diagnosed cancer patient. The slide reviews the definitions of each of the terms and provides an organization for students to use as they develop their arguments. In this slide, Julie also provided some direction for the type of reasoning that should be used for this topic, "science about how cells work," but the main emphasis of the slide is to remind students what should be included in a high-quality argument.

Figure 3

Julie's Google Slide for Scientific Argumentation



Scaffolds. To support students in writing scientific arguments, Julie used scaffolds to ease students into argumentation and support them in specific skills. Julie used one or more scaffolds in all of her units. Julie's first and last units included the most scaffolds. In contrast to direct instruction which occurred before students engaged in argumentation, Julie used scaffolds to support students as they made sense of argumentation such as giving them a structure to follow or allowing them to think through possible arguments informally in their scientific notebooks. After using one or more scaffolds, Julie had students develop a formal argument in all but one of her units.

Julie used two scaffolds most frequently: graphic organizers and notebook entries. In some cases, these scaffolds overlapped when Julie had students draw graphic organizers in their notebooks to gather information. For example, in the Climate Change unit, Julie had students draw a table with the headings “Claim” and “Reasoning.” As students examined multiple graphs and read the explanations, they identified the evidence and the reasoning for each text. Figure 4 shows an example of a CER graphic organizer Julie gave students for the first two argumentation units. In both units, students completed the graphic organizer before developing formal, written paragraphs for their claims.

Figure 4

Julie’s Graphic Organizer for CER

CER: Claim, Evidence, Reasoning Name: ___________________

Question	
Evidence from reading	Reasoning: Link to science ideas, concepts, principles
Claim (Your claim should answer the question.)	

In addition to gathering information, Julie used notebook entries to give students practice informally generating and revising their claim. For example, during the DNA unit, Julie prompted her students with the question, “Do you think DNA editing should be legal?” And prompted them to include the following in their response:

- “Explain the nuances of your answer: which organisms, for what purposes, after what kind of preparation/testing
- Support your position with scientific evidence and reasoning

- Include one counterargument and explain why your reasoning is stronger"

As Julie introduced more information or asked students to gather information from articles or videos, she had students revisit their journal entries or complete a new journal entry that incorporated their new data or new understanding of genetics. Julie noted that the intention of these informal argument practices was to help students in developing a more formal argument at the end of the unit.

> Throughout the quarter, I had them writing bits and pieces. Like okay, we just learned how does DNA get turned into proteins that create our traits. How does that knowledge help you answer the question: should we edit DNA? So, they wrote bits and pieces of this all quarter. And then at the end of the quarter, I said, you have all these pieces… take all those pieces and put it together.

Julie's description of this activity shows her intentions of scaffolding student thinking. Julie intended students to use the notebooks to gather their ideas in smaller pieces before synthesizing them together into one larger argument.

For longer units, such as the unit, "Should we Edit DNA?" Julie engaged students in small group and whole group discussions to help students generate and revise their claims. In both types of discussions Julie also incorporated questioning to help students in their informal argumentation practices. For example, Julie had her students turn in tables to generate claims about how scientists edit genes based on their knowledge of DNA replication. Julie used questions as the students discussed to help them think about scientific reasoning and evidence that applied the question. The transcript below provides an example where Julie was talking individually with one small group as they tried to generate a claim.

> **Student:** So, not the two ribbons that twist, but all those little bars, is that what you would replace?

Julie: Oh, okay. So, what makes up the bars?

Student: The letters, the bases.

Julie: The bases held together by hydrogen bonds, which is the part that encodes the information. What else do we know?

Student: So, on one side, well I guess on both sides… So, like, you know there's the ligase. So, the order of the bases is what changes the DNA, so if the ligase is separating them, could they like move those?

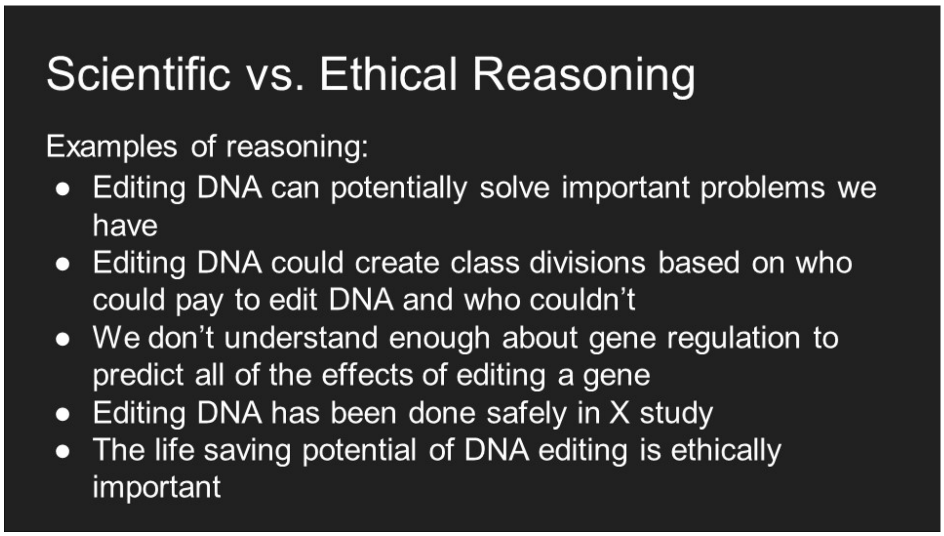
Julie: (to other students in the group): So, is that one possible way? Can I change the bases on just one side?

In this example, Julie prompted the students to think about the scientific knowledge they have to help them reason through the question. In this specific situation, Julie never confirmed to the students that they were right, though her questions implied to the students that they were headed in the right direction. Julie continued to rotate to each group, using questions to respond to students' ideas. Most of these questions prompted students to think about the information they had been observing in videos showing the process of DNA replication.

Finally, Julie provided examples for students to use as models for their writing, but only in the final unit where she asked students to write an argumentative essay about editing DNA. In addition to prompting students to include scientific principles to explain how their evidence supported their claims, Julie provided "Scientific Reasoning" sentences on a slide as a reference to students as they wrote. See Figures 5 for these reasoning examples. In discussing the models of ethical versus scientific reasoning, Julie emphasized that both types of reasoning could be used to support their claims on this topic and encourage students to use these sentences as possible templates for their own reasoning.

Figure 5

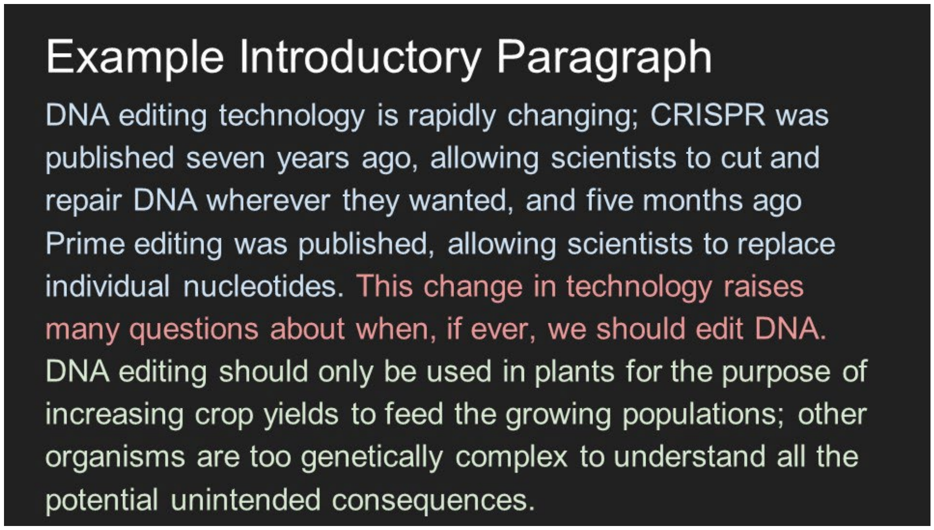
Julie's Model Scientific Reasoning



Julie also provided students with a high-quality introductory paragraph for students to use as a model for their own introductions. Figure 6 shows the color-coded paragraph. Julie used this model to show students what should be included in an introduction: an overview of the topic (blue text), the problem or question the essay will address (red text), and the thesis statement (green text). In discussing this model, Julie focused mostly on identifying the three parts of an introduction. She did not specifically tell students to use this as a template for their own writing, but the example was provided to students to use as they wrote their own paragraphs.

Figure 6

Julie's Model of an Introductory Paragraph and Thesis Statement



Julie's scaffolds tended to support students in two ways. First, the scaffolds such as graphic organizers and models reduced some of the rhetorical work of argumentation such as organization or wording. In doing this, Julie supported students in developing their arguments without being stuck on how to write an argument or how to word it. Second, the scaffolds such as questioning, discussions, and notebook entries allowed students room to engage in their own sense-making before committing to a single claim. Julie often concluded these informal argumentation practices by telling the students that she would not tell them her answer but wanted them to think about the best answer based on their current information. Julie implied with these types of scaffolds that claims can and should be adapted as new information emerged.

Feedback. Beyond providing a score or a grade to students, Julie also provided feedback for students in all but one unit. Julie's feedback was generally intended to help students improve on an upcoming argument. The one exception to this was the final unit, "Should we Edit DNA?" In this unit, Julie provided feedback throughout the lesson so that students could revise and improve elements of their argumentation before they developed it into a formal, written essay.

Julie provided multiple forms of feedback on her students' argument practices, but most frequently relied on annotations which included writing suggestions and comments directly on the students' written arguments. Julie also used color-coding as a form of annotation. For example, before beginning the argumentation unit "Human Impact on Climate Change," Julie returned the written arguments from the unit "Predator and Prey Regulation" which had the claim, reasoning, and evidence highlighted in different colors. Julie explained the color-coding orally before having the students check to see if they had all of the colors in the correct order. In both types of annotations, Julie's feedback was intended to help students see if they included all of the components of a high-quality argument.

Julie also used one rubric in her final argumentation unit. She co-developed the rubric with me as the literacy coach to evaluate both the content and the quality of the argumentation. See Figure 7 for the full rubric. In contrast to the feedback provided in previous units, the rubric provided feedback on the quality of the claim (which Julie referred to as a thesis in this unit), evidence, reasoning, and counterclaim.

Julie viewed the feedback on the rubric as more of an assessment of the students' essay rather than instructional feedback. In other words, Julie did not provide feedback that students could use to improve on a subsequent argument, but rather feedback that justified the score students received on their essay. In addition to the rubric, Julie also gave students the option of submitting their essays early to get feedback before submitting their final draft. Julie reflected on this, saying, "The kids who took advantage of that, took the feedback and did great things with it. So, I was very satisfied with being able to provide that support." Julie discussed the different purposes of her feedback in her final interview, saying,

> Also having a rubric where I'm reading and looking for particular things and I'm circling on a rubric is the most beautiful thing on the face of the planet. That saves me so much time. And being really clear about the purpose. Like, I used to be really bad about this, and I had an English teacher at my old school call me out on it. That, if it's a summative assessment, I shouldn't be giving feedback. Right, if it's a formative assessment and they can do something with it, if they can learn from it and change it, then feedback all over the place. But for that summative assessment, I didn't need to be writing all over.

Julie differentiated between feedback, which she viewed as a way to help students improve before they completed an assessment, and the rubric which she saw as more of a grade. In making this comment, Julie also acknowledged that time was an important factor in the type of feedback she chose to provide to students.

Julie provided feedback only on students' formal-written arguments. Though she had students engage in informal arguments like notebook entries and small group discussions, she did not provide feedback to students for these tasks. In reflecting on her instruction, Julie noted that students would benefit from oral feedback on discussions in her final interview. "Let the kids do it out loud, the argument part. And as they're doing that argument part, be listening for, 'Ah! That's a good piece of an argument'… I think this would help and I'm going to try it."

Figure 7

Julie's Rubric for "Should We Edit DNA Unit"

	4: Exemplary	3: Proficient	2: Partial	1: Limited	0: Missing
Biology Content: DNA Structure and Processes	You fully explain the structure of DNA, replication, transcription and translation, and gene regulation AND draw connections to how that allows for editing DNA for all topics. All vocabulary is used correctly and you include examples.	You explain the structure of DNA, replication, transcription and translation, and gene regulation AND draw connections to how that allows for editing DNA for most topics. All vocabulary is used correctly.	You partially explain the structure of DNA, replication, transcription and translation, and gene regulation. Most vocabulary is used correctly. The connection to DNA editing is weak or missing.	You explain some of the topics but not all. There is significant missing vocabulary. The connection to DNA editing is missing.	You do not explain any of the relevant topics.
Biology Content: Inheritance and Genetics	You fully explain DNA packaging, meiosis, allele interaction, and inheritance patterns AND draw connections to how that allows for editing DNA for all topics. All vocabulary is used correctly and you include examples.	You explain DNA packaging, meiosis, allele interaction, and inheritance patterns AND draw connections to how that allows for editing DNA for most topics. All vocabulary is used correctly.	You partially explain the DNA packaging, meiosis, allele interaction, and inheritance patterns Most vocabulary is used correctly. The connection to DNA editing is weak or missing.	You explain some of the topics but not all. There is significant missing vocabulary. The connection to DNA editing is missing.	You do not explain any of the relevant topics.
Scientific Argumentation: Thesis	Your thesis clearly takes a position on editing DNA. You bring in some complex thinking with your thesis statement (such as acknowledging the type of organisms).	You clearly take a position on editing DNA.	You take a position on editing DNA. Your statement might be unclear in places.	You include a thesis statement, but you don't clearly take a position on editing DNA.	You don't write a thesis at the beginning of your essay.
Scientific Argumentation: Supporting Evidence	You've chosen convincing scientific evidence. All of the evidence you've included directly supports your thesis.	Most of your evidence directly supports your thesis. Most of your evidence is convincing. You may have left out some important evidence or some of your evidence may not be directly aligned to your thesis.	At least two pieces of evidence directly supports your position on editing DNA. Some of your evidence might be unrelated or missing.	You include scientific evidence, but it does not clearly align with a position on editing DNA.	You may include general statements, but do not incorporate specific evidence into your essay.
Scientific Argumentation: Reasoning and Counter Argument	You incorporate scientific reasoning and clearly explain the connection to your position on the topic. Your topic sentences clearly set up the topic of your paragraphs. You have mentioned a valid counter argument and mentioned the strengths or weaknesses of this counter argument.	You incorporate scientific reasoning. Some of your explanations connect back to your position on the topic. Some explanations might be unclear or misrepresent the science. You have mentioned a valid counter arguments, but not the strengths or weaknesses of this argument.	You have some limited scientific reasoning. Your explanations don't clearly connect back to your position on the topic, but the connection may be implied. You mention a counter argument, but it may not be a strong counter argument for this topic.	You are missing scientific reasoning; you rely on ethical reasoning or the reasoning is unrelated to your position. Your counter argument is misrepresented or unclear.	Your mostly list evidence without including the reasoning connecting back to your position. You forget to mention a counter argument.
Writing Conventions: SPaG, formatting, citations	You clearly follow all of the guidelines provided. Your conventions and citations are correct.	You clearly follow all of the guidelines. You may have a few minor errors in conventions or citations.	You follow some of the guidelines. You have frequent errors in conventions and citations that do not make your meaning unclear.	You follow some of the guidelines, but frequent errors make your meaning unclear.	You don't follow any of the guidelines. Errors make your meaning unclear. Citations are missing.

Aside from one small-group discussion where students discussed their color-coded arguments, Julie was the only source of feedback for students. Students did not provide feedback to each other or self-evaluate their own arguments. This was another practice that Julie believed would have been beneficial to her students.

> One thing I've seen another teacher do that I'm very intrigued by I the idea of getting kids to grade, like highlight grade by color, their own arguments… So, they practiced on examples that weren't from class. Then she started having the kids start to grade each other's and give each other feedback. Which I think would be amazing for so many reasons.

Overall, Julie consistently provided feedback for all written arguments her students completed. This feedback was focused on helping students include all of the components of the argument structure, CER and CER+CC. This type of feedback is reflective of Julie's main learning goal for these activities, namely to develop students' argumentation skills.

How Julie's Experiences and Beliefs Map onto Her Instructional Practices

In addition to how teachers incorporated argumentation into their classes, I also wanted to see how their experiences and beliefs related to their instructional decisions and practices. For my second research question, I categorized each teacher's experiences from the initial interviews and coaching sessions into two categories: teaching experience and argumentation experience. I categorized beliefs into two categories: beliefs about science education and beliefs about scientific argumentation. For each section below, I examine how Julie's experiences and beliefs map onto her instructional practices. Julie's beliefs about argumentation became more developed and nuanced in the final interview at the end of the school year, so the final section addresses how Julie's beliefs adapted and developed after incorporating argumentation into her biology classes.

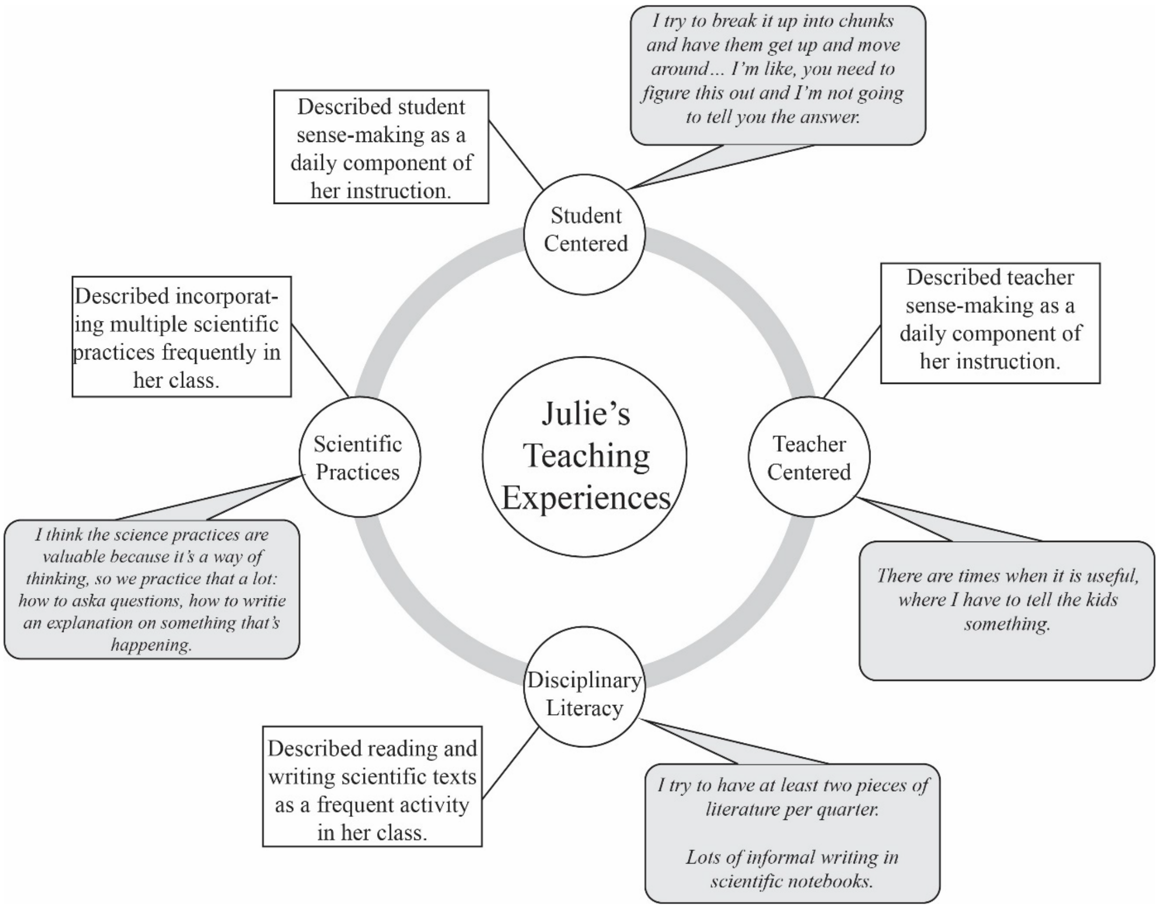
Teaching Experience

In looking at teacher experience, I wanted to see what types of instructional practices teachers frequently used in their classrooms such as teacher-centered instruction, or instruction where the teacher makes sense of the content for the students (Granger et al., 2012) and student-centered instruction, or instruction where students construct skills and understandings with support or guidance for the teacher (Serin, 2018). Teachers were asked to describe common instructional practices they used in in their classroom already to establish both their experiences and the classroom community the teachers created for the students. Julie had four years of experience as a science teacher and described commonly using student-centered instruction, teacher-centered instruction, disciplinary literacy, and scientific practices. Figure 8 summarizes Julie's self-reported teaching experiences and provides statements from her interview prior at the beginning of the study.

Student-Centered. In describing her common classroom practices, Julie reported having experience using student-centered instruction daily. Julie asked her students to discuss concepts in small groups and "grapple with ideas" in their scientific notebooks. Julie had created instructional symbols on her Google Slides to indicate to students that they were expected to make sense of the topic. In the corner of her slides, she wrote "table talk," for example, to let students know that they should be discussing their ideas in small groups.

Figure 8

Summary of Julie's Teaching Experiences



Julie's student-centered instruction also included giving students strategies to make sense of scientific information. For example, when describing her experience with vocabulary instruction she said, "a lot of my students were Spanish speaking so we would talk about the Latin roots and how knowing Spanish would help you know the Latin-[based] words." In this statement, Julie expressed her experience with showing students how to use their own experiences and knowledge to help them make sense of science.

Julie's decisions to incorporate multiple scaffolds for her argumentation tasks reflects Julie's self-described student-centered practices. Julie incorporated many of the same types of student-centered practices into her argument lessons. For example, Julie had students practice developing claims in their notebooks just as she had her students use notebooks to make sense of scientific principles in other units. Julie's other scaffolds such as graphic organizers and questioning students in small groups also reflect a student-centered instructional method. Students were given support and direction, similar to Julie's scaffolding of vocabulary instruction, but were required to determine their own claims and support them with evidence and reasoning.

Julie's students transitioned easily into student-centered argumentation activities which reflects Julie's experience in transferring sense-making to students. The students' discussion during her unit, "Should We Edit DNA" ended with Julie telling them, "That's an interesting thought. I am not going to answer your question right now," and directed them to continue thinking about the claims they had made as they learned more about the scientific principles behind editing DNA. The students were comfortable with Julie ending the discussion in this way rather than expecting her to provide them with the correct answers. In this way Julie's experiences as well as the students' expectations fit Julie's student-centered argument instruction. Notably, Julie did not describe such transitions as challenges to her argument instruction which may reflect both Julie's experience and established classroom procedures.

Teacher-Centered. Julie also described her teaching experience as teacher-centered, or directly explaining or making sense of the content for the students. She noted, "There are times where it is useful, where I have to tell the kids something." Julie gave several examples of her experiences in using teacher-centered instruction. In one example, Julie said, “I like to tell stories; stories are way more engaging than anything else.” Julie also noted, “I like to explain ideas and introduce vocabulary” before transitioning students into more student-centered practices. Like the student-centered practices, Julie also indicated on her Google slides that students should be listening and taking notes as Julie explained information to them. Instead of “table talk” in the corner of her slides, she included the words, “presenter talk” to let students know that they were expected to listen and take notes.

Julie’s direct instruction of the argument structures and argument terms echo Julie’s experience with using teacher-centered instruction. Julie began each unit by providing students with clear definitions and expectations for their arguments. Sometimes this teacher-centered instruction included a list of items to include. Julie’s feedback also reflected Julie’s experience in teacher-centered instruction. Julie directly told students what their arguments needed and directed them on how to improve them. Julie did not use student-centered methods of giving students feedback. For example, instead of having students compare their example to a high-quality example and identify differences, Julie chose to annotate the students’ arguments, instructing them on where and how to improve their ideas.

In both of the instructional practices above, Julie’s practices reflect her belief that students need to be told some information directly. In looking at the context of this instruction, Julie’s argumentation units generally followed a pattern that framed the activity with teacher-centered instruction, engaged students in student-centered understandings, then provided direct feedback with teacher-centered strategies. Julie described her common classroom practices as “chunks” where students moved from passive to active activities, mirroring her instructional decisions for argumentation.

Disciplinary Literacy. Argumentation often requires students to develop multiple disciplinary literacy practices including writing, reading and evaluating disciplinary texts, and researching (Goldman et al., 2016). Julie reported having experience in engaging students in disciplinary literacy practices including reading and writing scientific texts multiple times during each quarter. In reading, Julie often had students read multiple seminal scientific texts throughout the year. Describing her previous experiences teaching biology, she described having students read excerpts from Rachel Carson’s *Silent Spring* and excerpts from Charles Darwin’s journal. Julie also reported, “we read a scientific paper which is Watson and Crick’s letter to nature where they’re like, ‘this is the structure of DNA.’ It’s only two pages long, which is great for an introduction to scientific literature.” In addition to seminal scientific texts, Julie mentioned using multiple articles on scientific topics, graphs, and models to support students’ understanding of science.

Julie described her experience in using writing as mostly informal. In all of the courses she taught, she had students keep scientific notebooks where she had them include journals where they made personal connections, practiced creating models or diagrams, and wrote scientific explanations. “The goal [of scientific notebooks] was to have them summarize their learning at the end of class… they were reactions to things we were reading like, “How does this thing we learned in class matter to your life?” Julie used disciplinary literacy in writing to help students both connect to the content and help them make sense of what they were learning.

Julie's experience with engaging students in disciplinary literacy matches the way she designed her argumentation units. Each of the argument tasks used disciplinary texts as sources for the students' evidence and in some cases for their reasoning as well. Julie's unit about climate change described in Table 8, for example, provided students with a graph showing the relationship to the changes in the Earth's temperatures and possible factors such as deforestation. Notably, all of Julie's units used texts or teacher lectures as the sources for student arguments. Julie opted to use texts over other common sources for scientific arguments such as observations or designing and conducting experiments.

Julie's experience in having students frequently write in her class also reflects her decisions about her argumentation units. Julie relied on written arguments for all but one of her units including writing informally in their notebooks and writing formal arguments that were submitted for feedback. The exception to this one oral argument in small groups where students discussed the best treatment of a cancer patient. Julie also incorporated small group discussions to facilitate student arguments during her unit about editing DNA. This oral discussion served as more of a scaffold to give students ideas about counterclaims they could include in their essays rather than an argument in itself.

Julie self-described her experience with literacy as much more frequent than other teachers. She explained that "I'm kind of a stubborn brat, sometimes, and I refuse to give a final without short answers on it." This preference for having students explain their ideas and use writing over oral argumentation reflects her decision to rely mostly on written arguments in all of her units.

Scientific Practices. Finally, Julie described her teaching experience as including some of the scientific practices included in the Next Generation Science Standards

(NGSS; Lead States, 2013). Julie specifically mentioned using two scientific practices frequently in her classroom: "How to ask a question; how to write an explanation on how something is happening. We practice those a lot." Julie also reported having limited experience in using scientific argumentation. She had tried one scientific argument about whether Pluto was a planet the previous year. She described this experience as "sort of working."

During her interview, Julie frequently mentioned all eight scientific practices as essential, but only mentioned these two as common practices in her instruction at the beginning of the study. In discussing her experience at the end of the study through member-checking, Julie clarified that her instruction during the study also included using models and having students develop models. For example, she had students create models of DNA using Legos and had students model miosis using popsicle sticks. Julie's omission of this practice is likely because she did not connect modeling to argumentation, but clearly linked explanations and questioning to argument tasks.

Julie's experience in having students ask questions and define problems transferred to her instructional practices in argumentation. On her graphic organizers she used to scaffold argumentation for students, she included a section labeled "question" as seen in Figure 4. Julie also started each argumentation unit by having students "describe the problem" they were trying to solve.

Julie's experience in having students write scientific explanations is more closely tied to her instructional practices for argumentation. Julie distinguished explanation and argumentation from each other in that, "argument is different than an explanation because it is one thought higher than that, you could say." Her experience in having students write explanations in the past became the foundation for her instruction in scientific argumentation during this study. For example, Julie had students use a graphic organizer using the CER structure to write explanations in her previous classes. When she incorporated what she viewed as explanations during this study, she incorporated them with the intention of using them to develop students' argumentation skills. For example, Julie described having students write explanations about whether or not viruses were alive in her Earth science class.

> The first one I do is about whether viruses are alive. I don't turn this one into an argument, but you could very easily. Kids get to pick one of two claims. Yes, viruses are alive, or no viruses are not. Then I give them some readings and they learn about the characteristics of life. They get to pull out the evidence like one of the characteristics of life is DNA, but viruses can't reproduce by themselves and all living things reproduce.

Julie's first argumentation activity in this unit was the same question about viruses. Julie used this same activity as an introduction to argumentation in that she used it to introduce the CER argument structure and had students consider that "both explanations are valid" as a way to introduce how competing explanations create the basis of scientific argumentation.

During coaching sessions, Julie and I discussed how to use many of the same scaffolding and feedback strategies she had used for explanations in previous classes. For example, Julie mentioned her color-coding strategy that she used to help students see if they had incorporated all of the important components of a scientific explanation. Julie used the same type of feedback for her argument activities. Julie also continued using the CER graphic organizer that she used for explanations in the past. Even as she discussed with students how to address counterclaims in their arguments, she had them use the CER organizer to summarize each of the opposing explanations rather than create a separate graphic organizer for argumentation.

Julie's experience in scientific practices, especially in scientific explanations facilitated her argumentation instruction. Julie relied on many of the same scaffolds and feedback tools she had previously used. Julie even started with one explanation activity that she had previously used to help introduce students to argumentation. However, Julie did not describe her instruction as equally including all scientific practices. Julie did not mention engaging students in investigation as a common practice in her science classroom and her argumentation instruction relied more on gathering evidence from data represented in written texts or charts and graphs. In both of these instances Julie's previous experience in engaging students in scientific practices closely related to how she designed her argument tasks and how she supported students in argumentation.

Argumentation Experience

Argumentation, in addition to many other science practices, are often not part of the traditional science classroom (Drew et al., 2017; Duschl, 2008). As a result, science teachers who attempt to incorporate scientific argumentation may be teaching science in a dramatically different way than they were taught as students. In this study, I wanted to understand how the teachers' personal experiences with argumentation as students and their previous experience in teaching argumentation mapped onto the way they incorporated argumentation into their current classes. In this section, I first address Julie's experience with argumentation as a student, including her experiences at the university level. Next, I describe Julie's experience with teaching argumentation.

Student Experience. Julie described her own science education as "traditional" science instruction that was "so focused on the content that you lose a lot to the practices." She did not think of argumentation as a practice of science until she was introduced to the NGSS (Lead States, 2013) during her teacher training. When prompted, however, Julie, recognized that some of the practices she naturally engaged in were related to argumentation skills. She commented that in some instances when she was practicing science, she was engaging in argumentation activities "that were never named as argumentation and never formalized in any way." Below Julie describes two "informal" experiences she had as a university student and as a research assistant.

Julie described her experience of collecting data to look at the effect of bioeroding sponges on coral in Panama. After collecting data, she would discuss the project with the PhD student she was working for.

> We would walk back and forth, and we would talk about experimental design and should we do it this way, or should we do it that way? She taught me. She gave me some of the papers of other people who had done similar research and we said, you know, would you…Does what we're saying support this more or that more? But it was very informal as we were lugging jugs of water back and forth between the field station and where we were staying.

Julie emphasized the informality of this experience in that it was not called argumentation, it was not written down, and it did not fit the formal structure of a claim supported by evidence and reasoning.

After rethinking the example above, Julie added that she had in argumentation practice during her seminar classes in college. "We would bat around different interpretations of data and stuff like that." She also described working in a lab as a freshman in college where she engaged in informal argumentation:

> The only other real science experience was I worked in a lab doing, like, molecular research on some interesting proteins. And I think, again in a very informal setting. I did more work there with like, how would you set up an argument because we didn't actually get our data. We didn't actually, we were trying to get some E. coli to make a truncated protein, and we didn't actually transform the E. coli.… But thinking about like, if we had, what would we have learned and what data would we have wanted. And um, we spent a long time because we were, I was like, a freshman in college, so the professor spent a long time, like, having us think through that set up.

Julie's reluctance to label her "real science experiences" as argumentation may offer some insight into her instructional practices in argumentation in her classroom. First, Julie most often asked students to write formal arguments. When Julie offered feedback and evaluation of students' arguments, she did so on formal, written pieces rather than informal oral discussions or journal entries in student notebooks. This indicates that Julie saw argumentation as more of a formal exercise intended to improve students' argumentation abilities rather than a practice to help students engage in science in the same ways that scientists do. In other words, she saw "real science experiences" in which scientists discussed and defended the best design for a study or developed a claim about what the data in an experiment supported as separate from school argumentation.

This may offer some insight into the sources of data and reasoning that Julie chose for all of her argument activities. Julie had students use scientific texts, including existing data sets, and Julie's class lectures as the primary sources of the students' arguments. In each of these activities, Julie posed the questions for the students and then provided them with the texts where they could find evidence and, in some cases, reasoning to support their claim. Julie never had the students pose their own question, design their own method of investigation, or collect their own data from observations or experiments to support their conclusions.

Even though Julie had experience engaging in scientific argumentation, she did not see these experiences as transferring to the science classroom. This viewpoint was also reinforced through the model of literacy coaching in this situation. With a background in history and language arts, my own view of argumentation was also text-based, so rather than helping Julie to provide students with opportunities to develop arguments from other data sources in addition to scientific texts, I provided her with text-sets and ideas for text-based arguments.

Teaching Experience. Before the study, Julie described herself as a novice in using argumentation in her courses. She mentioned one experience prior to this school year that she described as "sort of working." In her earth science course with 9th graders, she asked students to develop arguments about whether Pluto was a planet. Julie's description of her one attempt to teach argumentation in the previous year informed her argumentation instruction.

> I had kids look at an explanation that Pluto should not [be a planet]. I had them look at an explanation that Pluto should be a planet. And we analyzed those looking for claims and evidence and reasoning. So, we didn't write those explanations, but we were looking at someone else's. We talked about the other planets, and this is what classifies them, and then we talk about Pluto: should it or shouldn't it be. I got a lot of kids being like, "Pluto is the best; it should be a planet," and I'm like, "Not scientific evidence. Not grounded in evidence."
> And I think part of the tricky part was that it was so based on how you define a planet that the kids were like the scientist. And it was pretty early in the year, so I didn't have anyone [who thought], "I am comfortable saying this is what the definition is, or this is what the scientist says it is. This is what the teacher says it is." I am curious to try it again with something that is not quite as, [dependent] on how we define it, and I would also probably want to talk a little bit more about the structure of an argument, that it needs to have evidence. I didn't tell them that, so that was a poor teaching move.

Julie's experience using argumentation gave her some insight into where students would struggle in developing arguments as well as the support they would need before developing their own arguments. Her comment about needing to provide students with a foundation in the structure of the argument was clearly a priority in how she incorporated argumentation. In all of her units, Julie began by explicitly defining or reviewing the structure of argumentation before having them write their arguments. Julie's argument tasks also generally avoided arguments that had to be grounded in scientific definitions such as how planets are defined. This reflects the lack of confidence Julie saw the students have in using definitions as reasoning in their arguments.

Beliefs About Science Education

Beliefs about the purpose of science education and the learning goals teachers have for students may affect their instructional practices (Bryan, 2012). The teachers in this study were asked about their overall purposes and learning goals in their biology courses, their beliefs about the best instructional practices and their beliefs about challenges in teaching biology. The following sections describe Julie's beliefs in each of the categories and how those beliefs map onto her argumentation practices.

Purpose of Biology. Julie believed that a biology course should help students develop skills and mindsets that they can use throughout their lives. For example, Julie said in her initial interview, "I tell kids I want them to learn how to take care of their bodies, how to take care of the planet. How to ask and take care of the planet. and in that I think the science practices are valuable because it's a way of thinking. "Julie's view reflects her belief about supporting students' skills above the content. She noted that classes that are too focused on the content, "lose space for kids to ask questions," which she stated as an important goal in her course. Julie also noted that, "I love the content," but prioritized her students' thinking and the application of science to students' lives.

Julie's stated purpose matched her description of common practices in her classroom. She listed both writing explanations and asking questions as frequent activities in her class.

In looking at Julie's topics for her argumentation unit, her purpose of getting students "to take care of their bodies" and "take care of the planet" are reflected in her choices. Two units focused on issues related to health such as deciding how much red meat is healthy to eat and determining the best treatment for a cancer patient. Julie also focused on some health aspects in her editing DNA unit. Julie also chose an argumentation unit about climate change, reflecting her goals for students to care for the planet.

Julie's incorporation of student-centered argument activities also reflects her goal for students to develop scientific ways of thinking. Her use of notebooks to help students generate and then revise claims reflects her belief that students should be able to question and change their thinking based on the evidence and data they are given.

Instruction. Julie mentioned multiple practices that she believed should be part of a science class. She repeatedly mentioned the eight scientific practices from NGSS (Lead States, 2013) as essential components of the science class to help students understand the biology content. In her words,

> I actually feel really strongly that teaching argumentation, or teaching scientific questioning, or any of those practices, out of the context of science is really kind of meaningless… So, the content without the practices is kind of meaningless in the same way the practices without the content is kind of meaningless.

When thinking about how often these practices should be part of science instruction, Julie said, "Well, there's only eight of them, so, one every eighth day, ish? They should always be there at some level."

Julie's beliefs about best instructional practices are reflected in her description of her common instructional strategies, especially having students ask questions, create models, and write scientific explanations. Julie did not report having students engage in mathematical computation or investigations as common practices in her classroom, which contrasts her belief that these practices should continually be brought in throughout the course.

Her beliefs do reflect her integration of argumentation in multiple ways. First, Julie did not use argumentation in isolation of the content. In all of her units, she gave content instruction to students before explaining or reviewing the argument structure. Her question for the argumentation unit was presented to students before she discussed the structure of the argument or explained how to use the scaffolds for the unit. Additionally, though Julie saw a connection between argumentation and explanation, she generally distinguished the other practices as distinct. Her comment that a practice should be incorporated about every eighth day implies that she saw the practices as activities that should be addressed separately from each other but connected to the same content. Julie kept her argumentation activities as distinct from any investigations, or modeling she had the students do. Although Julie had students write their arguments, she did not connect the students' arguments with communicating science to a specific audience. Instead, the written arguments were framed as activities to help students improve their argumentation skills.

Challenges. One challenge Julie mentioned was focusing too much on covering content. In other words, Julie worried about overemphasizing content knowledge rather than skills. She said, "I think I struggle too with a more traditional biology class that's so focused on content." She also noted that "a lot of standards have like way more content than you can fit in a school year anyway and there is pressure to cover it." Julie recognized that this was the way that she had been taught science, especially in secondary school and so she noted that balancing and blending the content and practices, which she viewed as best instructional practices, was a major challenge. Implied in this comment was also the limited time compared to the content knowledge included in her state standards for biology.

Additionally, Julie saw biology content in the standards that were abstract or unrelated to their lives. Below is Julie's response to what she believed was the biggest challenge in teaching biology.

> The content that's the hardest is the molecular stuff because it is abstract, and they can't see it. So, I preface that unit by saying in order to be a molecular biologist, you have to have a really good imagination because you are going to have to imagine a lot of stuff happening that we can't really see… I think it helps some kids. I think the molecular biology—I love it, but I'm a nerd. I think it is hard for them to see how relevant it is to their lives. Like the ecology stuff they see. Like animals eating other animals or animals eating plants. So, this is more immediate.

In this statement, Julie emphasized her love of content and the difficulty of helping students relate to it. In discussing challenges, Julie did not mention student abilities. Instead, she implied that these challenges were oriented in the standards. Julie's comments also reflect her viewpoint that these issues were difficult because she had not developed strategies to overcome them yet.

Beliefs about Scientific Argumentation

Researchers (Duschl, 2008; Osborne et al., 2004; Henderson et al., 2018) have noted that because many teachers were not taught scientific argumentation in school, they may not understand science argumentation themselves or be able to develop reasoning.

Additionally, teachers who do not see argumentation as valuable in their classroom may truncate or simplify argumentation (McNeill et al., 2018). To understand how the teachers' beliefs about argumentation mapped onto their argument instruction, the teachers were asked first to define scientific argumentation. Because all of the teachers saw themselves as novices in using argumentation, they were also asked to describe possible ways they believed argumentation could be incorporated into their classroom effectively. Additionally, teachers were asked what value, if any, they saw for using argumentation in their biology classes. Finally, teachers were asked to describe any challenges or barriers to integrating argumentation. See Appendix A for the initial interview protocol. Julie's beliefs about argumentation are described below.

High-Quality Scientific Argumentation and Instruction. Julie viewed argumentation in context of the NGSS (Lead States, 2013). She defined it as one of eight scientific practices that students should engage in throughout the year. In this context, she said, "arguments have a claim, evidence to support that claim, and reasoning that links the evidence to that claim." After defining argumentation in this way, Julie added that this was also her definition of scientific explanations and clarified,

> Just from that, that by itself could be a scientific explanation which is like explaining a phenomenon… So, if you have two explanations that are competing, for example, you could argue that one argument is more valid than another. You could argue that one explanation is incomplete, and you need more evidence. But it's still based on those science facts or your data. As opposed to like a debate club, where you can have an opinion, but science is more grounded in fact rather than an ethical framework.

As reflected in this quote, Julie saw evidence as specifically tied to scientific facts or data. She distinguished scientific arguments from those based on ethics or opinions.

Though Julie acknowledged that people made ethical arguments about scientific topics, she distinguished those from scientific arguments because in ethical arguments

> someone could hold a differing opinion that's equally valid and they can both be strongly supported by evidence. But in scientific argument there could be a wrong answer in that the argument would be that there is not enough evidence to say what is going on here.

Julie's defined scientific argumentation as a formal and structured process. This formal definition echoes her hesitance to call her own experiences as a research assistant or in laboratory settings argumentation because they were "never formalized in any way."

Julie's definition of a scientific argument was reflected especially in the structure she chose to use for all of her argumentation activities. For example, she used a non-domain specific structure adapted from TAP which included the three components of her definition of scientific argumentation: Claim, evidence, and reasoning. Julie's argumentation units also tended to focus on topics that helped students develop claims that were not based on opinions. The one exception to this was Julie's final unit where she asked students, "Should we edit DNA?" In this unit, students often brought in ethical reasoning to discuss their claims.

Julie's definition of argumentation also emphasized the inclusion of each component of argumentation as well as the amount of evidence. This definition reflects Julie's scaffolding and feedback which highlighted what should be included and gave feedback on missing components of argumentation. Julie's definition of argumentation centered less on the quality of each component which also reflects how she used both scaffolding and feedback in most of her unit.

Julie had some ideas on using argumentation in her classroom based on her experience teaching scientific explanation and her one experience attempting scientific argumentation. First, she emphasized that scientific arguments needed to be structured for students. She viewed structure as telling students what scientific arguments needed for support and clarifying what counted as evidence. She emphasized that students needed to understand that opinions would not count as reasoning, such as “Pluto is the coolest” and that reasoning should link the data to the claims.

Julie had multiple ideas for argumentation in biology specifically. She thought topics where there still was no scientific consensus, such as whether viruses are alive, would make good argument practices. She also thought that she could use historical examples where new explanations of scientific phenomena countered previously accepted beliefs such as Robert Pain’s starfish experiment that changed the belief about population control. Julie noted that another science teacher had told her, “Kids don’t care about it, so maybe it wouldn’t work so well,” indicating that argumentation topics should be engaging for students.

Julie’s integration of argumentation highlighted the structure of argumentation, clearly reflecting her views about instruction. Some of Julie’s views about structuring arguments came from her previous experience in which students thought that reasoning based on their opinions could be used as support. To avoid this, Julie always reviewed the structure, scaffolded arguments with organizers that included each component of argumentation, and in some units provided examples of what counted as reasoning or evidence for the question.

Value. Julie emphatically answered, “yes!” when she was asked if she believed argumentation should play a role in her class. She saw argumentation as providing students with valuable skills beyond the science classroom. She grounded this in her own experiences in non-scientific argument saying,

> I am really good at getting flustered and insecure when people disagree with me… and having a scientific framework gives it a structure so it is not the end of the world when you don't agree with somebody. It gives you a way to have a productive conversation saying my claim is different than yours… and it is grounding something in evidence and reasoning… It is really important, not just in science, but in life.

Julie's beliefs about the value of argumentation reflects her other beliefs including her belief that arguments should be structured as well as her belief that science should provide students with skills beyond the science content.

Along with her other beliefs, Julie's heavy focus on structure in her integration of argumentation echoes her beliefs that having a structure allows people in disagreement to have productive conversations. In contrast to this belief, Julie's argument activities rarely had students develop arguments as a response to opposing positions. Even when Julie added counterclaims to the argument structure students were using, she often had students generate their own counter-claims.

Julie had one exception to this in her final argumentation unit. To support students' counterclaims in their essays, Julie had students share their claims in small groups followed by clarifying and critiquing questions. Julie framed this activity by saying,

> Two things to think about as we do this one, it can be uncomfortable to say what you think and know that other people might disagree with you. I am terrible at disagreeing with other people. It makes me very uncomfortable. We need to get better at being able to disagree with each other and for it to be okay. The other thing is focus on the person's ideas. Not on the person. Can I pick on somebody? All right. So, let's say Sam has a thesis that is totally opposite of mine. We completely disagree. It is absolutely okay for me to say, Sam, I don't agree with your idea. I think it's flawed because of this, this and this. I can tear Sam's ideas apart. It is not okay for me to go straight to you. I think you are a terrible human

> because you think that. Do you see the difference between focusing on someone's ideas and focusing on them as a person? Yeah. Focusing on attacking someone as a person is a really good way to shut down debate because then everyone's all defensive and then you're not going to get anywhere.

Julie's instructions to students about how to disagree reflects her own discomfort at argumentation and her belief that structuring debates for students can help them develop production conversations when they disagree.

Challenges and Barriers. Julie described the main challenge to argumentation as helping students understand how claims, reasoning, and evidence should work together. Julie based her description of this challenge on her experience teaching scientific explanation to students. She described her students as "flinging claims over and over again." She said her students were yelling, "'This is my claim and it's better'. 'But this is mine and it's better.'" She continued her description saying that students were "throwing definitions at each other and not agreeing. Their evidence does not match, right?"

Julie's evaluation of this instance was a reflection on her own instruction. She noted that she had not structured the argument or helped students think about how definitions could be used as reasoning in their explanations. She specifically explained that she assumed students knew that scientific claims needed to be supported with scientific facts.

Julie's Changes in Beliefs About Scientific Argumentation

Julie's understanding of argumentation and her ideas for using argumentation remained essentially the same in the first and second interviews, but her ideas about the features of high-quality arguments and the best ways to teach argumentation were clarified and in some cases extended.

Julie continued to emphasize the importance of claim, evidence, and reasoning in high-quality arguments, but she emphasized the importance of addressing alternative explanations in arguments. At the end if the study, Julie believed that good argumentation instruction should help students differentiate between the components of argumentation both in developing their own arguments and in consuming arguments. She explained that students should be able to point out, "this part is the claim. This part is a piece of evidence supporting the claim. This part is reasoning supporting that evidence. Um, is really important both in writing an argument and in reading somebody else's." This instructional element is similar to Julie's beliefs at the beginning of the study, but it emphasizes a student-centered approach to teaching argument structure and evaluating argument structure.

In addition to helping students understand the general structure of argumentation, by the end of the study, Julie also believed that students needed additional support in data collection.

> Particularly in a scientific argument, you have to be able to interpret the data. You have to be able to look at the graph and say, this is what the graph means, and this is why I know this is what the graph means, um, so that the data interpretation piece is really key.

In this excerpt, Julie emphasized disciplinary literacy skills in being able to interpret information from multiple formats such as graphs. As opposed to simply including all of the components in argumentation, Julie recognized that students need to understand the texts they are using for data to improve the quality of the evidence in their arguments.

Julie similarly expanded her discussion about student reasoning. She mentioned reasoning as one of the more difficult components of argumentation.

> Yes, in like a specific argument, or even just in explanations, kids really struggle with what counts as reasoning. Like, I have a claim and I have a piece of evidence... Yes? And, like, how are those two things connected? Telling me the moon is made of cheese because Peyton Manning's passing rate is XYZ is not useful. So, reasoning is hard.

In all of these examples, Julie continued to emphasize the importance of using the CER structure to support students, but her instructional practices developed beyond simply helping students include each component and helping them develop the quality of each component.

Julie also added to the CER structure by including counterclaims. She mentioned the importance of helping students develop the ability to evaluate multiple arguments as an essential skill to developing their own arguments.

> And then the other part of an argument that I kind of forgot about right until this second, is to be able to look at an alternative explanation. And so, a counterclaim in some ways, is almost like a second argument. It also has to be supported with evidence. It also has to have logical reasoning to link that evidence to the counterclaim. Um, and just because a counterclaim is somewhat different than yours, or totally different than yours, doesn't mean that like, it's not logical. And there can be logic in opposing explanations, in both of them. And how to use evidence to refute someone else's argument. I think that was initially more complex than I gave it credit for.

In this comment, Julie recognized that students need to look for the strengths and weaknesses in all potential explanations when creating a scientific argument. Julie realized that students often ignored important and legitimate claims in alternate arguments, leading to both weaker arguments and potential misunderstandings of a phenomenon because students did not fully evaluate other positions. Julie reflected, "It was really hard for my kids to look at someone who disagreed with them and learn anything from it, I guess, and say like, oh that makes sense, but I think you're missing this part over here."

Julie's beliefs about supporting students in critiquing arguments was also more developed in the final interview. Focusing on feedback, she believed that listening for the quality of argument during oral activities would be helpful both in giving students feedback and developing students' ability to evaluate and critique arguments.

> And as they're doing that argument part, to be listening for, like, "Ah! That's a good piece of an argument." or "Ah! That's actually argumentation." Why do you think it actually is argumentation? I'm curious if this would have helped a lot of the things is having them critique others' arguments. So, I don't know if I can give that as advice of like, this worked for me! I think this would help, and I'm going to try it. To help them feel like there can be common ground between explanations.

Julie also mentioned some changes to the ways she incorporated feedback. She mentioned the importance of timing when providing rubrics. Though she supported students with graphic organizers, an outline, and modeling, without the rubric giving them specific standards of what they were writing, the students were frustrated.

> Because I didn't have the rubric done until I was at the very end. And I think that would have helped. I think I had a hard time articulating what I wanted it to be. There were kids who were frustrated because they were like, I don't know what you want me to write.

Finally, Julie clarified the differences between oral argumentation and written argumentation. She saw oral argumentation as a potential scaffold for students' written argumentation, so they should be given more opportunities to make oral arguments with feedback before transitioning to written arguments.

Summary of Case 1: Julie

Julie saw argumentation as a valuable practice in science classroom. She incorporated argument activities into every quarter of her instruction. The findings for research question one showed that Julie's emphasis for most of her argumentation units was on the structure of argumentation. Julie used direct instruction to define the components of argumentation at the beginning of each unit; she used scaffolds to help students include all of the components before writing their arguments; and she used feedback before the next argumentation unit to help students recognize missing or incomplete argument components.

Julie's teaching experiences blended seamlessly into her argument instruction. She shifted between teacher-centered to student-centered practices during her argumentation units much in the same way she did while teaching other content or skills. Julie's decision to use scientific texts as the main source of data and reasoning for each of her units matches her experience with supporting students in reading scientific literature. Similarly, her choice to focus on written argumentation as her primary mode of argument connects to her use of writing in all of her units. Julie's previous experience with teaching scientific argumentation also mapped onto her direct instruction, the scaffolds she used, and the type of feedback she provided.

Julie's beliefs about science education and argumentation were apparent in how she incorporated argumentation into her class, outweighing some of her personal experiences using argumentation to do science. Julie's beliefs about the most important learning goals in science education were reflected in the topics she chose for argumentation units. Julie's beliefs about what makes high quality argumentation, and the best instructional activities were also closely tied to her emphasis on the structure of arguments. Importantly, the way Julie defined argumentation in school played a larger role than her own personal experiences of authentic argumentation. Because she believed argumentation should be clearly structured, often formal, and written, she chose not to have students design an investigation or gather data from observation in order to answer a question.

Julie's beliefs about argumentation, especially best practices for teaching argumentation, developed over the course of the study. While continuing to believe that high-quality arguments should be structured, she noted additional skills that students needed support in developing. Her views shifted from focusing on whether or not students could identify and include claims, evidence, and reasoning to helping students accurately interpret data, improve the quality of their reasoning, develop better understandings of counterclaims, and be able to critique their own and other's arguments. These changes reflect a better understanding of the skills students need to create high-quality arguments after incorporating argumentation for three quarters.

Case 2: Jordan

At the start of this study, Jordan had taught for 18 years at both the middle and high school level. Jordan had the second-longest experience of teaching science of the four teachers in this study. Jordan had taught both chemistry and biology at both schools with a Composite Biology Teaching degree. In his previous high school, he had also taught an honors level biology course. Jordan was also the science department head at the time of this study. Though Jordan was an experienced teacher, he was beginning his first year of teaching Advanced Placement (AP) Biology, so he was creating new curriculum throughout the year. He was in the unique position of being an experienced teacher, but a novice in teaching this particular course.

Jordan was familiar with modified TAP (CER) framework but had little experience using it with his students prior to this study. Jordan had previously worked with me as a literacy coach to help students read and evaluate scientific texts in his biology classes. Of all the teachers, I had worked with Jordan most frequently in previous years, both in developing and adapting curriculum to support students' reading and in modeling and team-teaching instruction. In working with me during this study, Jordan was often overwhelmed with teaching AP Biology for the first time, and his coaching sessions were usually short and often unscheduled such as during lunch or during breaks at parent-teacher-conferences. Jordan was one of two teachers that asked for me to model an argumentation lesson in one of his classes before he taught it to another class.

Below, I first focus on how Jordan integrated argumentation into his instruction including the types of argumentation units and instructional practices he used (how), when he incorporated the practices into his instruction, and his learning goals and purposes for the argumentation units (why). Next, I address my second research question, looking at how Jordan's experiences and beliefs mapped onto his decisions about incorporating argumentation into his class. I specifically describe Jordan's experiences in teaching and argumentation as well as his beliefs about science education and scientific argumentation. Jordan's beliefs about argumentation became more nuanced and developed by the end of the study, so I conclude Jordan's case with a description of his beliefs after incorporating argumentation into his class.

Jordan's Integration of Scientific Argumentation: How, When, and Why

The intention of my first research question was to look at the ways each teacher incorporated argumentation into their class. I developed codes to describe the strategies the teachers used to engage students in argumentation, in other words, how the teacher integrated argumentation. When teachers had multiple argument activities dealing with the same topic or question, I grouped these activities together as a unit. The first section below looks at the design of each of Jordan's argumentation units such as how argumentation was defined for students as well as other key features like the duration of the activity, the class groupings, and the type of data students used for evidence. These findings came from the transcripts of Jordan's observations, coaching sessions, and artifacts. The second section describes Jordan's instructional practices including when Jordan used each strategy and his purposes for each strategy.

Overview of Jordan's Instruction and Design of Argumentation units

Jordan primarily incorporated argumentation as mini-lessons throughout the year. Jordan reported using argumentation two to three times per quarter. I observed four mini-lessons which made up three separate argumentation units. The remainder of his argumentation activities were completed as part of tests or assigned as homework practices for students. Jordan provided students with feedback on these assigned argument practices but did not discuss them in class. These were usually practice questions reflecting the Free-Response Questions (FRQ) that students would see on the AP Biology exam at the end of the year.

For the last quarter Jordan planned on incorporating an argumentation unit in which students would develop and support claims about Kettlewell's methodology in his study of moths. He also had planned additional writing activities as preparation for the AP exam, but he changed his plans because of the sudden shift to online instruction due to COVID-19 school closures. The features of Jordan's argumentation units that he incorporated earlier in the year, including the structure, mode, duration, and groupings, are summarized in Table 9.

Jordan's first three argumentation units were taught at the beginning of the year. Two units took place during the first quarter and the third was incorporated at the beginning of the second quarter. For Jordan's analysis, I used the three argumentation units that I observed as well as notes from coaching sessions and the artifacts from these three units.

Table 9

Case 2: Features of Jordan's Argumentation Units

Argumentation units	Argument Structure	Style	Mode	Duration	Source of Data/ Reasoning	Class Grouping
Case Study: Cystic Fibrosis & Cell Membrane	CER	Formal	Written	Mini-Lesson	Scientific Text	Individual
Gaucher Disease	CER	Formal	Written	Mini-Lessons (2)	Scientific Text	Individual Small Group
Mitochondrial Disease	CER	Formal	Written	Mini-Lesson	Scientific Text	Individual
Advanced Placement FRQ*	CER	Formal	Written	Homework or Test (4)	Scientific Text	Individual

*Free Response Question

Jordan introduced a general argument structure, CER, to his students during their first argumentation unit. He continued to use this structure for each of his subsequent units. Jordan's argumentation lessons were consistent in most of the features including mode, duration, data sources, and groupings. The one exception to his lessons was the second lesson in his unit, "Gaucher Disease." In this unit, Jordan included a follow-up lesson to help students evaluate the quality of their arguments which varied from the other units by incorporating small-group discussions.

Jordan's units all required students to write formal arguments independently. Jordan did not have students engage in any oral argumentation or informal argumentation (impromptu arguments without clear requirements for format, content, or organization). All of the arguments were framed as preparation for the AP exam. Additionally, none of the units took an entire class-period (80 minutes). Instead, they were mini-lessons within a larger content unit and lasted between 30 to 40 minutes.

Jordan used scientific texts that included case studies, background information, and graphs as the source of data and reasoning in all of his argumentation units with no student generated data such as data from an investigation or experiment.

Jordan's Instructional Practices for Scientific Argumentation

Jordan used effective instructional practices to integrate argumentation including direct instruction, multiple forms of feedback, and some scaffolding (Dawson & Carson, 2020). Table 10 shows the instructional practices Jordan used for each unit.

Table 10

Case 2: Jordan's Instructional Practices by Unit

Argumentation unit	Direct Instruction	Scaffolds	Feedback
Case Study: Cystic Fibrosis & Cell Membrane	Defined CER	Graphic Organizer	Annotations
Gaucher Disease	Reviewed Identified CER	Graphic Organizer Questions/prompts	Annotations Small Group Eval. IRE Questions Open Questions
Mitochondrial Disease	Reviewed CER Listed Inclusion Criteria		Annotations
Advanced Placement FRQ* Assigned			Annotations

* *Not observed*

Direct Instruction of Scientific Argumentation. Jordan began his argumentation instruction by defining the CER structure. Jordan introduced this structure with a non-scientific topic about boy-bands to teach students each part. He asked students to make a claim about the best boy bands and support their ideas with evidence and reasoning. In reflecting on this during a coaching session, Jordan recognized the drawbacks of this activity.

> We went through [argumentation] together, like with a cheesy example. The best boy bands of all time. I was trying to make it more fun—I need to find a better example because they were distracted by boy-band songs and stuff like that.

Before each of the next units, Jordan reviewed the definitions of CER before having students develop their arguments. In the example below, Jordan clarified the definition of evidence in his second unit.

Jordan: Um, what is evidence? What does that mean?

Student: Support your claim

Jordan: Support your claim, sure!

Student: Stuff from the article?

Jordan: Stuff from the article, yeah! So, is this just stuff that you make up?

Student: It's like quotes

Student: It's like facts!

Jordan: Yeah, these are facts. And in science it's usually something that's been observed. It's not somebody's opinion, right? So, it's something that's pretty concrete and observable and fact-based.

In this exchange, Jordan confirmed the students' definitions of evidence and clarified evidence specifically used in scientific arguments.

Later in the year, Jordan had students identify and evaluate the claim, evidence, and reason in samples he provided to the students. During this identification task, he focused on the quality of each component such as a claim that clearly answered the question; specific, related evidence; and reasoning that relied both on accurate scientific principles and provided a logical connection between the reasoning and the claim. For example, in the second lesson in the "Gaucher Disease" unit, Jordan discussed an anonymous student's reasoning, emphasizing that good reasoning must connect back to the claim.

> So, a couple of things. Did they refer back to their claim in their reasoning? The fact that it's an inherited disorder, did they mention that at all? Or even some word that is not inherited, but means inherited? No, they didn't. So that's one big thing that they're missing is that they didn't connect to their claim in an obvious way. So, you've got to really make sure that you do that.

In this example, Jordan asked the students questions that he directly answered for them before directing students to improve the quality of their own reasoning. This direct instruction, like most of Jordan's direct instruction, occurred just before students were assigned a new, unrelated argumentation task. Jordan's instruction was intended to help students improve their argumentation in upcoming arguments but was not intended to help students revise a previous argument.

Jordan's purpose for direct instruction was to both emphasize the structure of argumentation and how to make each component of the structure high-quality. Jordan presented these purposes to students in terms of success on the AP exam. For example, in discussing what constituted high-quality claims, he said,

> Did they answer the prompt? Yes, they answered the prompt. They did, alright. Is there one right claim on this article? Yeah, no. That's kind of the nice thing about these, that there's no one right claim. Did they answer the prompt? That's what you've got to see.

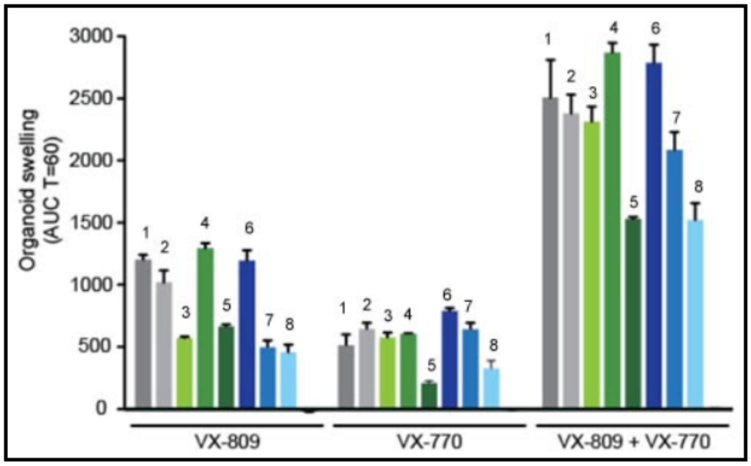
In this statement, Jordan is referring specifically to a practice prompt similar to what students would see on the AP exam. He explicitly links high-quality claims to answering prompts on an exam rather than defining high-quality claims in terms of scientific arguments.

Scaffolds. Jordan provided students with scaffolds primarily to support their understanding of the argument structure. He used a graphic organizer with the CRE framework on the first argument practice to familiarize students with the structure. Jordan had the students fill out the graphic organizer before submitting written arguments. Students then continued to use this structure without the graphic organizers on subsequent written arguments.

Figure 9

Excerpt from Jordan's Cystic Fibrosis Argumentation unit

20. The graph below shows how each drug works for 8 different patients (#1-#8). Organoid swelling indicates the effectiveness of the drug at moving Annotate the graph and provide a short 1 sentence caption that summarizes the main idea being illustrated by the graph.



21. (CER) If the profile labeled #7 is Zoey, rank the possible drug treatments in order of their effectiveness for her mutation. This is your **CLAIM.**

Provide **EVIDENCE** to support your claim

Provide **REASONING** that explains why this treatment would be more effective than other treatments and why what works for Zoey may not work for other patients. This is where you tie the graph above to everything you have learned in this case and to information about the cell membrane and cell processes.

*See Appendix F for the full handout (Muskopf, 2020)

Jordan also used questioning as a scaffold for students. He incorporated written guiding questions on the scientific texts they analyzed to help them identify the claims, evidence, and reasoning made in the articles. With these questions, he gave reminders about what students should include for each argument component. He also used guiding prompts to help students interpret and use data from graphs and diagrams to support their claims. Figure 9 shows an example of the guiding prompts Jordan adapted from an online case-study to help students understand the information on a graph about Cystic Fibrosis (CF) before writing an argument about what would be the most effective treatment for a child with CF. In the “Reasoning” portion of the argument task, Jordan specifically mentioned cell membrane and cell processes to remind students that their reasoning should include scientific principles to justify their claims.

Jordan’s scaffolds tended to support students’ understanding of the argument structure, or the definitions of each component. Jordan’s graphic organizers, questions, and prompts helped ensure that students included all three parts of the CER structure. In some cases, the questions and graphic organizers included reminders about how to write a claim or what types of information should be referenced in the reasoning section.

Feedback. Jordan also provided multiple forms of feedback for his students ranging from whole-class feedback to individual feedback on each students’ assignment. Jordan preferred annotations on students’ arguments over rubrics because he wanted to give individualized feedback to each student. He noted that rubrics were often too general and did not accurately describe what individual students were doing.

> I tried really hard to not just click a box on a rubric, but to say something else to help them, and that’s what takes time to give the feedback and comments. Because a rubric is good to a point, but it’s not always specific to what the kid writes.

Jordan’s feedback was intended to support students on their next arguments rather than provide feedback for a revision. Jordan expected students to transfer the feedback from one argument to the next argument.

During whole group discussions, Jordan also used questioning to provide feedback. He used Initiate-Respond-Evaluate (IRE) questions where he confirmed that the students’ answers were right or wrong. Jordan paired the IRE feedback with his direct instruction of both the structure and the quality of argumentation. For example, Jordan had students look at an anonymous student sample and asked, “So, in the claim, did they do it? Did they talk about how it's caused?" After students responded, Jordan confirmed they were correct saying, "Yeah, they did. I would give that one actually a thumbs up." Jordan used this IRE pattern to provide feedback both on the sample argument as well as feedback on the students' evaluation of the argument.

Jordan also used open-ended questions where he asked the students to discuss what they noticed with a partner. He asked, "What do you notice about the reasoning in this example?" Jordan used these open-ended questions to prompt student-based feedback of sample student arguments. Jordan alternated between open-ended questions that allowed students to develop their own assessments of each argument and the IRE questions where Jordan indicated whether their assessments were correct or not. As referenced above, Jordan had students use a thumbs up or down to vote as a whole class before he gave his evaluation of the argument. Jordan used both forms of questions for two purposes. First, the students were given immediate feedback on their ability to critique the quality of a scientific argument. Second, students could use the strengths and weaknesses of the sample arguments to inform their own upcoming arguments.

Jordan provided feedback for all of the argumentation units including the homework and test practices he assigned. Jordan's feedback was focused on providing information on how well each component of the argument, the claim, evidence, and reasoning, worked to create a high-quality argument. In some cases, Jordan noted if a student omitted a part of the argument structure (such as forgot to include reasoning), but most of his feedback was intended to help students improve the quality of the claim, evidence, and reasoning, such as whether the reasoning accurately linked the evidence to the claim.

How Jordan's Experiences and Beliefs Map onto His Instructional Practices

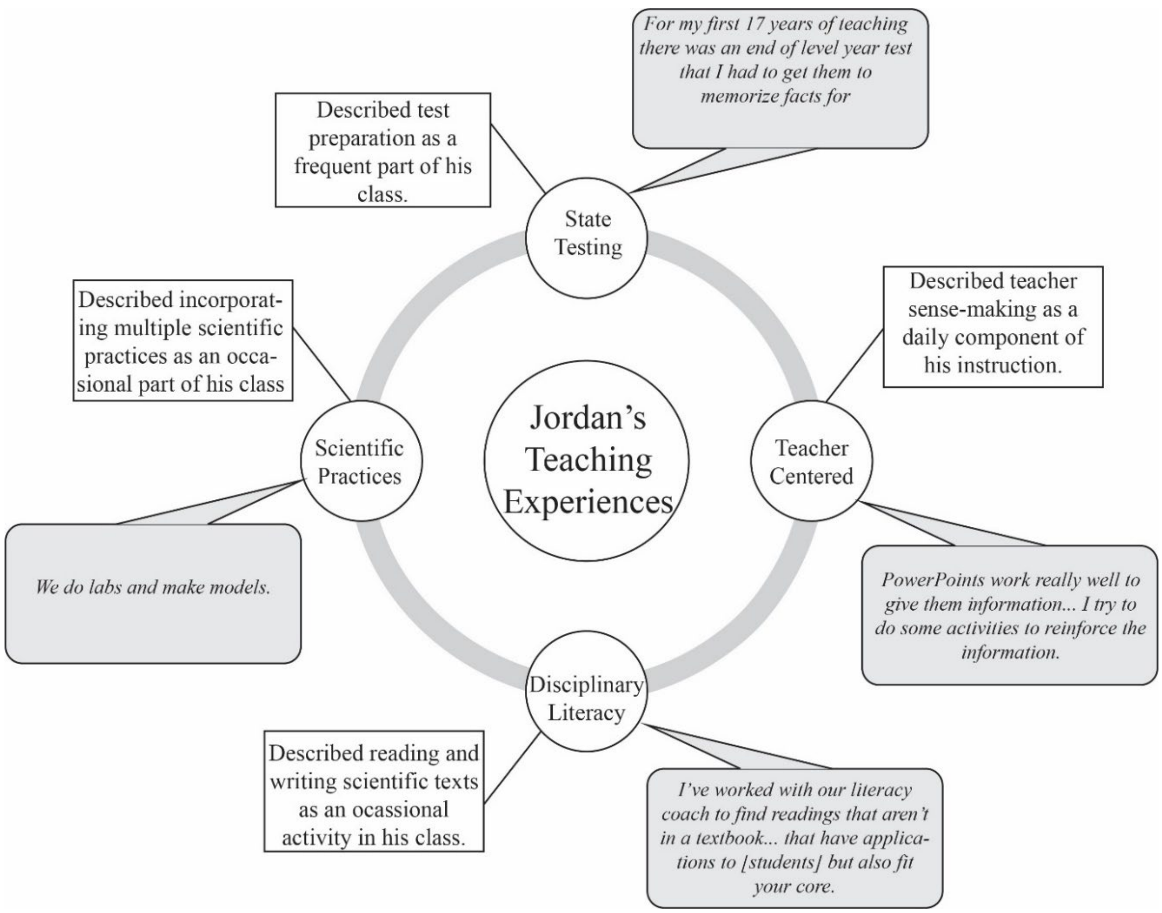
In addition to how teachers incorporated argumentation into their classes, I also wanted to see how their experiences and beliefs related to their instructional decisions. For my second research question, I categorized teacher experiences that they described in their initial interviews and coaching sessions into two categories: teaching experience and argument experience. I also categorized, their beliefs into two categories: beliefs about science education and beliefs about scientific argumentation. For each section below, I examine how Jordan's experiences and beliefs mapped onto his instructional practices for argumentation. Jordan's beliefs about argumentation became more developed in the final interview, so the final section addresses how Jordan's beliefs changed after incorporating argumentation into his biology classes.

Teaching Experience

Introducing new instructional practices can be a challenge for teachers when the practices differ significantly from their usual approach (Wang & Buck, 2016) both because the teacher may not have the strategies to facilitate new practices and because the students may have expectations based on their previous experience in the teacher's classroom (Berland, 2011). To understand how the instructional practices each teacher used for argumentation related to their previous experience, the teachers were asked to describe the instructional practices they used most frequently in their science classes prior to this study.

Figure 10

Summary of Jordan's Teaching Experiences



Jordan had 17 years of teaching experience in multiple schools and described using teacher-centered practices, disciplinary literacy, test preparation, and scientific practices. Figure 10 summarizes Jordan's teaching experience at the beginning of the study.

Teacher-Centered Instruction. Jordan described his instruction as primarily teacher-centered. He stated that he often started each unit with a PowerPoint lesson "to give them the information." Jordan said he reviewed this information with a quiz at the beginning of each class to help students practice recall. He encouraged students to take notes from his class lectures. In contrast to a student-centered notebook where students could practice making sense of science, Jordan reported having students draw or write information that he gave to them in a whole-class lecture.

Jordan reported often adding in labs “to reinforce” the information he presented. “If you can’t do a lab, we try to do some sort of activities to reinforce it.” While labs may often be student-centered in science classrooms, the way Jordan described his labs was generally teacher-centered because it was a way to confirm the content he had already given the students. The students were given expectations on what the lab should prove or show rather than completing the lab as an investigation to a question or a problem. Jordan then described ending each unit with a teacher-led review of the information followed by an assessment. “We do a review and take a test.”

Jordan’s argumentation units were often embedded within teacher-centered activities. Jordan’s choice to use argumentation as mini-lessons rather than full day instruction or multi-day units fit into his traditional classroom practices. For example, in one mini-lesson providing feedback on the arguments students had written about Gaucher’s disease, Jordan embedded the student discussions about the quality of sample arguments between a review of the previous day’s lesson and a lab to reinforce that information.

Jordan’s instruction of argumentation remained predominantly teacher-centered. The argument tasks that Jordan chose seemed to replicate the way he used his lab activities: to reinforce science concepts Jordan had previously taught. The first three argument mini-lessons all focused on case studies of diseases that served to reinforce information Jordan had presented to them in a lecture. For example, students wrote arguments about a two-year-old with a potential mitochondrial disease after learning about heredity and mutations.

While Jordan continued to rely on teacher-centered instruction, students did engage in student-centered learning as they developed and supported their own ideas through written arguments. Jordan noted, however, that the students were often "regurgitating" information from their notes or from the accompanying texts rather than interpreting the information as evidence or reasoning to support their claims. Because Jordan had set up a teacher-centered learning environment, he described students struggling to interpret information in a way that justified their claims. To support students in this, Jordan added in a follow-up lesson in his "Gaucher Disease" unit to help students make sense of what quality arguments should look like. He incorporated open-ended questions, had students discuss examples in small groups, and asked students to make their own assessments of several anonymous examples. This lesson was co-developed with me as the literacy coach. Jordan asked me to model this style of teaching before he taught the same lesson with a different class.

Jordan's experience with teacher-centered instruction was ingrained in his teaching style. His argument instruction reflected these established practices. Because scientific argumentation requires students to make sense of science in order to support their ideas, Jordan and his students struggled to transition between teacher- and student-centered learning.

Test Preparation. Much of Jordan's teacher-centered instruction was given with test preparation in mind. Jordan explained, "My problem is that for my first 17 years of teaching, there was an end of level test that I had to get [students] to memorize facts for."

While Jordan did not see test preparation as an ideal way of teaching, the majority of his experience had been in preparing students for a standardized, multiple-choice test at the end of the year.

To prepare students for the test, Jordan prioritized memorization of facts over hands-on or exploratory learning. He had students take quizzes at the beginning of every class and used multiple-choice tests to assess students' learning. Jordan described his experience as "pressure to cover" everything, and not having the time to do more "fun activities." Jordan also described his experience in this kind of instruction as contributing to "kids taking a science class and say they hate science, and I don't want them to do that."

Although the state where Jordan taught had ended the subject-specific state tests for science, Jordan's course during this study was intended to support students on the AP exam at the end of the year. Because of this, Jordan's argument instruction was also focused on test preparation. One distinct difference between the test preparation for this exam compared to Jordan's previous experience was that the AP exam included written responses as part of the exam and specifically listed argumentation as one of the skills students would be assessed on (Collegeboard, 2020). Jordan still felt pressure to cover content, however, and so he chose to do short argument practices that closely reflected the types of written responses students would see on their final exam. After the second quarter, these argument practices were primarily homework assignments or test questions with no accompanying class lessons or discussions.

Disciplinary-Literacy. Jordan reported that he had done some reading and writing in his biology courses prior to this year, often working with me as a literacy coach to develop student-friendly scientific texts and to support students in reading strategies specifically helpful for these texts. Though he had incorporated some of these activities into his course, he noted that this was not a common practice in his class. He mentioned multiple trainings in reading instruction throughout his teaching career but recognized that these trainings generally did not result in changes to his instruction. He reflected that the trainings "give me a guilty conscience that I need to do more reading with my students. I mean, they get us pretty good ideas, but I tend to get back to my rhythm and forget."

Jordan reported little experience in writing, noting "I've neglected [writing] a lot over the years because it takes time." This lack of time also reflected the pressure Jordan felt to cover content for the state test which focused on multiple-choice rather than written responses.

Jordan's limited experience echoes the challenges he described as he integrated argumentation that will be discussed in more depth below. Jordan expressed frustration at his own limitations in teaching writing both as part of the argumentation units as well as other types of scientific writing.

Scientific Practices. Of the eights scientific practices of the NGSS (Lead States, 2013), Jordan reported using two of them frequently. He described having students create models and he frequently mentioned labs, however, Jordan described his labs as reinforcing his lectures rather than investigating a problem or a question. Jordan's labs were usually set up for the students to follow step-by-step so that they could have a better understanding of the science content. Jordan described these labs as most common in his chemistry class and not as frequent in his biology class.

Although Jordan mentioned both models and labs as important components of his science courses, he did not combine either of these practices with argumentation. This reflects, in part, Jordan's experience in teacher-centered instruction. His models and labs were generally used to confirm information rather to help students investigate a problem or a question to help them develop claims.

Argumentation Experience

Jordan was familiar with scientific argumentation as a way to support student learning of scientific practices, but he had little experience with scientific argumentation both as a student and as a teacher. Jordan remembered his science instruction as memorizing facts. "It was like, this is how it is. Remember it." Jordan's experience as a student was similar to the way that Jordan described his own common practices. Jordan remembered very little writing as a science student, either argumentative or other types of writing.

Jordan had some limited experience in using scientific argumentation in his own instruction. This was primarily test preparation for the ACT college entrance test (ACT, Inc.) to help students identify evidence, claims, and reasoning between two different explanations of data. "There is a question that says two different scientists—one says this, and one says this. And then they ask the students questions about it." Jordan had helped students understand the two claims and how they related to the data provided with the questions. Jordan also mentioned that he told students about historical scientific arguments in his lectures. "We have gone through historic stuff a little bit to show what happened," but he did not have the students evaluate the different arguments or develop their own positions. Jordan also mentioned using socio-scientific topics related to ethics in previous courses. "I have done some debate type deals especially when you are talking about ethics and genetics. Like should you be able to clone someone or not? Clone your cat? Just little things like that."

Jordan's limited experience in both learning and teaching science argumentation were reflected in the challenges he described at the end of the study. Additionally, Jordan's description of helping students evaluate two different explanations was also informed by a standardized test that all high school students in his state were required to take. As noted above, Jordan's primary purpose for incorporating argumentation during this study was also informed by a high-stakes test.

Beliefs About Science Education

Teachers' beliefs about the goals of science education can play an important role in understanding their instructional practices (Pimentel & McNeill, 2013; Wang & Buck, 2016). To understand Jordan's beliefs about science education, I included questions in the initial and final interviews asking teachers to describe their main goals and purposes for science instruction. Additionally, teachers were asked to describe their beliefs about the best instructional practices for helping students learn science. See Appendices A and B for the interview protocols. Beliefs can also be inferred from conversations and instructional practices (Bryan, 2012), so I also used transcripts from coaching sessions and observations to get an understanding of teachers' beliefs about the purpose of biology, best instructional practices, and challenge to teaching science.

Purpose of Biology. Jordan's main goal for his science instruction was to get students to enjoy science and his class. Jordan believed that the memorization of facts for exams had led to student disengagement and disinterest in science. "I think [my science instruction] should be better because I don't want them to hate science because too many kids take a science class and say they hate science, and I don't want them to do that."

Jordan also had new goals for his AP course compared to his previous biology classes. He wanted to immerse students in the scientific experience to help them understand how to do science rather than learn about science. Part of this goal came directly from the AP learning goals. "AP really stresses that they want to get away from factual recall." He noted that students should be pushed towards "scientific thinking: reasoning through things. You know, you are presented with some information, and you have to reason it out."

Jordan's beliefs about the most important learning goals in science directly contrasted his reported teaching experiences. When looking at Jordan's learning goals for argumentation, his previous teaching experience aligned more closely than his beliefs about what science education should be.

Instruction. Jordan's common practices did not align directly with what he thought good science instruction should be. He mentioned specifically that he should give students more opportunities to make sense of science rather than directly telling them. "So ideally," Jordan said, "you have them discover the facts for themselves and hopefully they come to the right conclusion. So, I guess as much as you can do, that is a good thing." Jordan emphasized that students still need to have the right conclusions. "You've got to make sure they don't get too far off. You would let them do that [discover facts] and just be sure they don't come out with the wrong information." Jordan's description of good science instruction in these quotes shows both his belief that his instruction should be more student-centered, but also stresses his concern that students accurately learn scientific principles.

Jordan also mentioned that he thought he should have students engage in more hands-on activities that would help make science more interesting to them. “Some of the topics, I need to make more interesting. Like genetics they all perk up because they are all interested in that, but when you have to talk about cells, they are not quite as interested in that.” In spite of Jordan’s goals to allow students to take a larger role in making sense of science, the pressure he felt to cover content led him to continue his teacher-centered practices including in the way he incorporated argumentation.

Additionally, Jordan’s concerns that students do not misunderstand the science content reflect his use of argumentation as a follow up activity to his lectures. He had students apply scientific concepts to related case studies, but rarely had students develop arguments about a scientific phenomenon. For Jordan, this reduced the risk of misconceptions and helped students apply knowledge that Jordan had presented to them.

Challenges. Jordan noted multiple challenges he experienced in teaching biology. Jordan saw challenges with the biology content as well as challenges reaching the students. Jordan believed that science should have hands-on and engaging activities, but he saw “finding enough hands-on stuff to do in biology” especially difficult. “The concepts we teach, [hands-on learning] is harder to do in here.” Jordan’s view that biology was difficult to engage students using labs, designing experiments, or gathering data from observations likely reflects his decision to use texts as the sole source of data in his students’ arguments.

Jordan also emphasized the students at the high school as a challenge. He described his students' disinterest in science and school in general as a major challenge. "Apathy, that's another biggie," Jordan responded when asked about previous challenges in teaching biology. He recognized that for "some of the topics, I need to make them a little more interesting." For Jordan, though, the students' lack of engagement informed his instructional choices.

> So, when I taught at my last school, it was kind of an honors, gifted program and they liked debates. With those kids, I used to try and do more fun activities... I have noticed since I came here, these guys are like, "give me the easiest path from here to here." If you want to make them do something more, they struggle with it, so I have not pushed it as much as I should have.

Jordan's decisions about incorporating argumentation echo the challenges he described for teaching biology at this high school. Jordan chose to have students write arguments individually. He did not have students do oral debates or complete arguments that required complex steps such as designing an investigation or gathering evidence from an observation. Jordan's concern that students struggled with activities that required them to do more than passively receive information also reflect his choice of using argumentation activities to confirm the content in his lectures.

Beliefs About Scientific Argumentation

Beliefs about scientific argumentation may also be related to teachers' instructional practices (Zohar, 2007). Teachers' beliefs about what good arguments should look like, the best practices for helping students learn argumentation, and the value they see in argumentation may cause them to create or adapt curriculum in specific ways (McNeill et al., 2018). To understand Jordan's beliefs about argumentation, I used the initial and final interviews to directly ask about high-quality scientific argumentation and instruction, the value of scientific argumentation in biology classes, and the challenges and barriers he saw in implementing scientific argumentation. See Appendices A and B for the interview protocols. Jordan's beliefs about scientific argumentation were also inferred from discussions during coaching sessions and statements Jordan made during instruction. Jordan's beliefs about argumentation developed over the course of the study, so I end this section with a comparison of Jordan's beliefs at the beginning and end of the study.

High-Quality Scientific Argumentation and Instruction. Jordan understood argumentation specifically through a scientific lens. He noted important features of scientific argument as compared to other forms of argument. He also viewed scientific arguments as dealing with both arguments about scientific phenomenon as well as socio-scientific issues. Jordan described scientific argument in a disciplinary way.

> I guess my understanding is especially from science as a frame of reference. You got two people who have fairly valid ways at looking at something. And science— in some cases you don't know exactly what it is and sometimes it takes years to figure it out. So, two people with fairly valid explanations are arguing— seems like they are trying to get mad at each other— but I guess if I think of a scientific argument, I hope that they are not getting mad at each other. I hope it's like, I think my way is a better explanation than your way, so there is a little bit of a disagreement about [who is right].

In this quote, Jordan is addressing the difference between scientific arguments as attempting to reach the best explanation rather than common views of arguments that imply contention and anger. He clarified this further stating, "They both think they are right, I guess, because they both try to support their claim that they are right."

Jordan understood scientific arguments to have a claim and support. He did not clarify what counted as support or what should be included in scientific arguments during this interview, continuing to use the two broad categories of claim and support. He primarily viewed scientific arguments in terms of historical examples noting “I know more historical stuff because that’s what we teach.” He provided this example to express his understanding of scientific argumentation:

> For a long time, there were people that thought life spontaneously occurs… and there was a scientist that came in and did an experiment that said no, it has to come from other things. And then there was this other goofus who did a bad experiment, and it said that, “oh look life does spontaneously occur” because he did it wrong. So, it set that back for a couple hundred years. Until someone said, “no life does not spontaneously exist.” And so, there was that argument that exists. Life has to come from other life it doesn’t just occur.

In this example, Jordan’s understanding of scientific argumentation emphasized the importance of the quality of experiments that support a scientist’s claim. Jordan went on to explain that scientific arguments are often limited by the type of information that is available to scientists.

In addition to viewing scientific argumentation as differing explanations of a scientific phenomenon, Jordan also saw scientific argument as arguments about the application of science in socio-scientific issues. For example, he noted that scientific arguments can include arguments “like when you’re pushing technology, what’s ethical to do?”

Jordan’s direct instruction of argumentation often highlighted components that he believed were important, such as the reliance on facts as evidence. Jordan opted not to use socio-scientific argumentation in his class, which reflects his focus on preparing students for the AP exam which would not ask for this type of argument. One unit that Jordan and I collaborated on asked students to make arguments about the methodology of a famous study about peppered moths. Though Jordan chose not to use this activity when students went to online learning, the planning of this unit reflects Jordan's beliefs that the methodology of a study is an important consideration in scientific argumentation.

In teaching argumentation, Jordan believed engagement was crucial for using argumentation in his classroom.

> You've got to make sure the topics, I guess, are easy for them and something they will be intrigued about. There are some topics as a scientist you can argue about, but as a kid, it's just like, "I don't care about the toad that lives in Zions National Park."

Jordans beliefs about science instruction relate to his beliefs about the challenges for teaching science. He believed that topics should be interesting to students. Jordan tried to make his argumentation practices related to real life experiences. For example, when asking students to make an argument about mitochondrial disease, he posed the question as though the student were talking to a relative about her child who was showing symptoms.

Jordan also believed that some controversial topics in biology were focused on ideas that are well-established in the science community. He believed that bringing up topics like endangered species or climate change should focus on the actual argument that exists among scientists rather than the ways that the topic is debated outside of science.

> In ecology, you get some conservation issues that people really don't like, like endangered species, and, you know, climate change and things like that. People want to have an argument on evolution, but from a scientific standpoint there are arguments about how it happens, but the argument that people want to do are just, does it happen? And that's just certain among the science community. But that is something that… with natural selection how it happens. The mechanism for it, sure there is some debate there.

Jordan's descriptions of possible topics for his classroom indicates two things about Jordan's ideas on instruction. First, he did not see the value in having students engage in controversial topics where the claim has been established by the scientific community. Jordan did not clarify if he believed this should be true for all topics in his course, but especially for topics where he saw misconceptions in the mainstream, he did not want students to engage in those types of arguments. Second, Jordan did want students to think about topics where the science had not reached a consensus, such as the mechanism for evolution. In discussing using the ethics of technologies as a possible topic, Jordan noted, “That’s an area I feel it really fits because that’s something there is definitely not a right answer. It’s a hard answer.”

Even though Jordan wanted students to engage in these types of topics, Jordan did not have students debate anything that was currently undecided or currently being debated in science. Much like his decisions about instructional practices, when Jordan’s beliefs were at odds with his experiences, such as focusing on arguments for test preparation or focusing on arguments that were engaging for students, Jordan tended to default to his experiences over his beliefs.

Value. Jordan saw value in argumentation as a practice in biology but balanced that value against the importance of reaching the right conclusions in argumentation. “I think [argumentation] is good. I think there are some things you’ve got to make sure they don’t get too far off, like a eukaryotic. It has a nucleus, so there’s no argument there. It has a nucleus.”

Jordan primarily used arguments that were applications of information that he had previously taught. This fit with his concern that information primarily needed to be taught directly and argumentation should deal with concepts where misconceptions were not as big of a concern. Jordan framed arguments similarly to how he defined arguments: a claim with support. He did provide students with definitions of high-quality arguments that included reasons and evidence, which was not a part of his definition. Though he saw arguments in science as focused on the quality of the evidence gathered (such as the types of experiments), he primarily had students reach claims using facts that were presumed true. For example, in having his students make an argument about the primary cause of Gaucher's disease, he had them refer to the knowledge of cell structure and function as reasoning and the data about what was happening to the body as evidence.

Challenges and Barriers. In the initial interview, Jordan anticipated multiple challenges and barriers with incorporating argumentation into his instruction. His main concern was that "If you have them argue it out too much, there will probably be some misconceptions. [Teachers should] just be sure that students don't come out of it with the wrong information." Second, Jordan believed that if the argumentation was not engaging enough, then students would struggle with the difficulty of doing something more than passively listening to science lectures.

Jordan's Changes in Beliefs about Scientific Argumentation

Jordan expanded his description of high-quality arguments at the end of the year, especially in describing the support arguments needed.

> I guess I'd never really paid attention, which is good. I mean, I taught using evidence-based, like to back up your sources, which I guess is a good thing. But this has just been a good refocus, especially in the AP class that I was looking at. I've got to remind my students, you know hey, you've got to back up your answers. You can't just say it and assume people... I mean, they can connect two and two, a lot of people that are reading it, but you shouldn't assume that. You've got to use-- you've got to point it out at them to be good at [argumentation].

Much of Jordan's comments about high-quality arguments at the end of the study centered around the importance of evidence and reasoning, as in the example above. He especially saw evidence and reasoning working together rather as distinct components of argumentation. “So, it’s not just having the evidence and a claim, but it’s taking it and providing the reasoning to connect the two.” Though Jordan mentioned evidence and reasoning before engaging in argumentation throughout this unit, his discussion of the terms became more specific and student-oriented. Additionally, Jordan’s emphasis on convincing the audience with valid reasoning brought up the purpose of argumentation as a persuasive practice, not just an evaluation of student knowledge.

In terms of instructional practices for argumentation, or pedagogical content knowledge (PCK), Jordan’s description about teaching argumentation were also more specific and focused on student needs than his discussion of instruction at the beginning of this study. Initially, Jordan described limited strategies for facilitating argumentation other than finding engaging topics. At the end of the study, Jordan recognized that students needed time to practice the skills of argumentation and develop their ideas. “It takes a little bit of time to write a good [argument]. To have a claim, if you will, and then back it up with evidence. They just want to get done as fast as they can.” In this statement, Jordan noted that student effort was one major barrier to teaching argumentation. Jordan was also describing the importance of giving students time and supporting them in using that time to develop high-quality arguments.

Jordan also talked about scaffolding at the end of the year, something he did not mention in the beginning.

> Well, I think it’s to walk them through an example of it at the beginning. Like that whole scaffolding is, you’ve got to—cause most of them are just going to—like I tried it without it at first, because I was just unaware, and they did very poorly to start. And so, it’s good to have an example, a really good one, to walk them through, I think.

He believed that starting with something simple, “something that’s not complicated at all; it’s very easy to find evidence, it’s very each to connect claim and evidence; walk them through it very well. And then baby step getting more complex.”

Jordan’s ideas for instruction often related directly to activities where he thought he could improve, such as saying, “I started too complex.” He also referenced instances where students struggled with argumentation to justify his ideas for the best practices in teaching argumentation. Unlike the beginning of the year, Jordan’s ideas for instruction were more focused on developing the skills of argumentation rather than focusing on the content of argumentation.

Jordan also saw more value in argumentation in his classroom, not only as preparation for an exam, but as an important skill for understanding science in daily life. He specifically referred to the current situation of COVID-19 in thinking about the value of argumentation in his class.

> I mean, looking at the more I learn about it, like we’re switching to the different standards this upcoming year. And I know that they want us to do more of this type of a thing where, yeah, it’s the claim, evidence, reasoning model sort of a deal… It really is good. Being able to— I mean even if you just look at this COVID stuff, right? You’ve got to be able to back up a claim with evidence and then explain it so that people believe you and believe the data. So, it’s a, it’s a very important skill to be able to have, sure.

This was a specific change from the value he saw previously to using argumentation. While he also saw argumentation as potentially beneficial to his students at the beginning of the year, he mostly framed it in terms of understanding science. Along with that, he emphasized the importance of making sure students did not have misconceptions about important scientific facts. At the end of the year, however, he noted that the skill of backing up claims with evidence and providing convincing explanations was essential itself.

Jordan's description of high-quality argumentation in the beginning of the study was primarily focused on choosing topics that would be engaging for students. He did not describe instructional strategies to support students in argumentation such as scaffolding. Since he saw the main value of argumentation as a tool for teaching scientific concepts, he expressed some concern about argumentation leading to misunderstandings. By the end of the study, Jordan clearly articulated multiple instructional strategies to support students in argumentation, largely based on both success and failures he experienced throughout the year. In addition to teaching scientific concepts, Jordan also saw argumentation as an essential tool for improving students' critical thinking and reasoning skills that would help them interpret science in everyday situations.

Summary of Case 2: Jordan

Jordan believed argumentation was a valuable practice for science, but his beliefs often did not match his previous teaching experience. Jordan incorporated argumentation mostly in ways that reflected his experience rather than his beliefs about science education and argumentation. The findings for research question one showed that Jordan's purpose for his units was primarily test preparation and confirmation of science content that he had previously taught. Jordan tended to use teacher-centered instruction in his argumentation units including direct instruction of both the structure and the quality of argument components, scaffolding to ensure that students included claim, evidence, and reasoning in their arguments, and feedback to help students improve the quality of their arguments, especially their reasoning. Jordan's instructional strategies placed emphasis both on structural aspects of argumentation, or including all the parts, and on the quality of each component.

Jordan's teaching experiences clearly reflected his instructional choices. First, Jordan's main teaching experience was in preparing students for a high-stakes test at the end of the year. Jordan's incorporation of argumentation was also intended to prepare students for the AP exam at the end of the year, so he modeled his argument tasks on the types of questions that students may see on the exam. Second, Jordan used argumentation in the same way he had used other scientific practices such as modeling and labs: to reinforce scientific concepts that Jordan had already lectured on. Using argumentation in this way also avoided an important worry that Jordan had about students developing misconceptions if they were not told the information directly. Finally, Jordan's teacher-centered instruction made moving students towards the more student-centered practice of argumentation challenging.

Jordan's beliefs about science education and argumentation were often at odds with his experiences. Jordan's beliefs about how science should be taught and how argumentation should be taught did not match up with the features of the argumentation units or his instructional practices. When Jordan's beliefs and experiences did not match up, his experiences tended to inform his instruction rather than his beliefs.

Finally, Jordan's beliefs about argumentation instruction and challenges developed over the course of the study. Jordan's beliefs about how to teach students argumentation recognized both the complexity of argumentation and the importance of scaffolding students into argumentation by using simpler topics first. Jordan also recognized that students may need more time than the short mini-lessons he used during the year. In contrast to Jordan's ideas at the beginning of the study which focused mostly on what topics he could use to support argumentation, Jordan's description of best practices for teaching argumentation shifted to thinking about the skills that students needed to develop. Jordan continued to view argumentation as a valuable part of learning science, but also emphasized the importance of argumentation in helping students make sense of science in their everyday lives.

Case 3: Mitch

At the start of the study, Mitch had previously taught one year of biology and an elective genetics course at the same high school. He was the least experienced of the four teachers in the study. His bachelor's degree was in biology. He was also an assistant football coach and was working on his master's degree in health science. Mitch was still developing his curriculum and instructional practices at the beginning of this study. During the first quarter, Mitch was often required to be at football meetings or practices before and after school. He commonly expressed pride in being able to figure things out on his own.

During the first collaborative coaching meeting with all four biology teachers, Mitch was outspoken. He asked a lot of questions, often joking about his inexperience. Mitch offered many ideas in this first discussion, mostly focusing on socio-scientific arguments. He easily generated ideas for argumentation that required students to apply their knowledge to a current problem such as invasive species in a local national park. Mitch had little experience in having his students make arguments in his biology class, but he had asked students to debate controversies about genetic engineering in his elective genetics course the previous year. Mitch was eager to try new instructional strategies, but often lacked the time to plan and evaluate his lessons. Mitch often implemented argumentation suddenly without giving me much notice. His debriefing sessions were usually short because he had to leave for football practice or after school weightlifting.

Below, I first describe how Mitch integrated argumentation into his instruction including the types of argumentation units and instructional practices he used, when he used them, and his learning goals and purposes for them. Next, I address my second research question: How did Mitch's beliefs and experiences map onto his instructional decisions? I begin with Mitch's teaching and argumentation experience followed by his beliefs about science education and argumentation. Mitch's beliefs about scientific argumentation, specifically the value of argumentation, changed at the end of the study. I conclude this case with a description of the changes to Mitch's beliefs about argumentation.

Mitch's Integration of Scientific Argumentation: How, When, and Why

The intention of my first research question was to look at the ways each teacher incorporated argumentation into their class. I developed codes to describe the instructional strategies the teachers used to engage students in argumentation, in other words, how the teacher integrated argumentation. The first section below looks at the design of each of Mitch's argument tasks such as how argumentation was defined for the students as well as other key features like the duration of the activity, the class groupings, and the type of data students were using for evidence. Argument tasks were separated by the topic and grouped into a single unit. These results came from the transcripts of the observations, coaching sessions, and artifacts. The second section describes Mitch's specific instructional practices, when he used the practices, and why he used them.

Overview of Mitch's Instruction and Design of Argument Tasks

Mitch intentionally completed three argumentation units over the course of three quarters with one unit lasting multiple days. Mitch also supported students' argumentation skills unintentionally through daily class warm-ups in which he had students read and respond to scientific articles. Though Mitch did not view these warm-ups as part of his argumentation instruction until he reflected on his instruction in his final interview, I included these activities in the discussion of Mitch's argumentation instruction for two reasons. First, Mitch used argumentation terms in many of these daily warm-ups. For example, he asked students to identify the hypothesis, claim, position, or main finding in the articles. He also asked students to make and support claims from the article, evaluate the evidence and reasoning in the article, or make a claim about the methodology in the article. Second, in reflecting on his own instructional practices during Mitch's final interview, he brought up these activities as examples of argumentation instruction, though not in terms of argumentation as he came to understand it. The features of Mitch's argumentation units are presented in Table 11.

Table 11

Case 3: Features of Mitch's Argumentation Units

Argumentation units	Argument Structure	Style	Mode	Duration	Source of Data/ Reasoning	Class Grouping
Is Water Wet? Intro. to Arg.	CER	Informal	Oral Written	Mini-lesson	Internet Search	Whole Class

Human's Role in climate Change	CER	Informal	Oral Written	Single-Day	Teacher Lecture Scientific Text	Individual
Police Access to DNA databases	Debate Format*	Formal	Oral	Multi-Day (3)	Internet Search	Whole Class
Daily Science Articles*	Varied	Informal	Written	Mini-lesson (daily)	Scientific Texts	Individual Whole Class

*See Appendix H for debate format
* When these were assigned, Mitch did not identify this as argumentation

In the first two argumentation units, Mitch used the CER framework, but he moved away from this structure for his longest argumentation unit. This final argumentation unit focused on a socio-scientific issue and was structured around a debate format. Mitch emphasized terms like critiquing the opposing view, defending a side, and evaluating sources, but beyond his structure for the debate, Mitch did not provide a clear structure for argumentation. Mitch assigned students to one of two positions randomly. Mitch also assigned roles to every student including devil's and angel's advocates who were responsible for looking up counterarguments and developing refutations for them. Other students were responsible for finding evidence, developing opening and closing statements, and note-taking during the debate.

Mitch most frequently required students to make arguments in whole group settings. His first two argumentation units were informal whole group discussions during which students filled out graphic organizers for their claims. Mitch did not ask students to write arguments beyond filling in graphic organizers. Mitch incorporated one formal (arguments with clear requirements for format, content, and organization) oral argument that lasted two class-periods (160 minutes total).

Mitch's primary sources for data were both internet searches and scientific texts. In the first unit, the internet search was optional. If students could not think of evidence to answer the question, "Is Water Wet," Mitch encouraged them to look online for ideas. In the whole class debate about genetically modified organisms (GMOs), students were directed to search the internet for evidence and complete a Google Slide template with information. Additionally, Mitch provided students with scientific texts, such as in the "Human Impact on Climate Change" argument where he had students look at multiple graphs and explanations to fill in their graphic organizers. Mitch also provided students with scientific articles daily and asked them to identify or evaluate the claims. Notably missing in the sources are data from investigations conducted by the students such as conducting experiments or gathering data from observations.

Mitch's Instructional Practices for Scientific Argumentation

Mitch used multiple instructional practices to support his students in oral argumentation. He incorporated direct instruction about the structure of arguments and criteria for high-quality arguments, oral feedback, and some scaffolding. Table 12 shows the instructional practices incorporated into each of Mitch's argumentation units.

Table 12

Case 3: Mitch's Instructional Practices by Unit

Argumentation unit	Direct Instruction	Scaffolds	Feedback
Is Water Wet? Intro. to Arg.	Defined CER	Graphic Organizer Questions	Oral Feedback

Human's Role in Climate Change	Identified CER	Graphic Organizer Questions	
Police Access to DNA databases	Described critiquing sources Described how to counter-arguments Described organization	High-quality Examples	Oral Feedback
Daily Science Articles*	Identified CER	Questions	Oral Feedback

Direct Instruction. Mitch used direct instruction to define argumentation and to teach the CER structure of argumentation in the first two argumentation units. First, Mitch asked students to define argumentation and confirmed their responses, saying that argumentation is "a fight, an issue, a disagreement." He continually used combative language to define argumentation during this introductory unit and in the two units that followed. Second, Mitch embedded the definitions of claim and reasoning into a whole class discussion of argumentation. Mitch defined claim and reasoning orally as students volunteered examples of claims. Mitch did not provide students with a written definition of any of the CER structure. As Mitch asked students to offer claims, evidence and reasoning, he provided two definitions of claims at various times in the whole class discussion including, "You're claim is going to start with a yes or no. So, your claim is, 'Yes, water is wet'" and "claim is a statement, a one sentence statement." Mitch also defined evidence as students presented their ideas. His main definition of evidence was, "Evidence: That is some kind of experiment, some kind of data that explains your claim or justifies it." Mitch defined reasoning as, "This ties your evidence and your claim together," and reasoning tells me, "Why is your evidence good enough? How is it good enough?"

Mitch described high quality argumentation as being made up of a claim, evidence, and reasoning. He emphasized that "you need to understand that you need to have all three of these. If you just have a claim and evidence… someone can interpret that evidence however they want, so you need to give them a reason." Mitch emphasized high-quality argumentation during his first two units as having all of the necessary components. Later in the year, however, Mitch defined high-quality arguments differently. During the final argumentation unit, Mitch emphasized good argumentation as winning against an opposing side. For example, Mitch emphasized argumentation as a series of won or lost points:

> If you are losing a point and you are absolutely getting trashed and you're like, "Ain't no way I'm going to win this point." It's okay to say, let's go back to this or let's go over here. It's kind of like, you can lose the battle and still win the war. You can lose the point and still with the debate. You don't have to win all the little arguments. That's why some groups are winning or losing.

Mitch's direct instruction of high-quality argumentation in this case brought back how he defined argumentation in his first unit: as a fight with a clear winner and loser. This definition also changed his description of high-quality argument from having a claim, evidence, and reasoning to how well students defended themselves against critiques regardless of the validity of their position.

Scaffolds. To support students' oral and informal written argumentation, Mitch used scaffolding in all of his units. Much of Mitch's scaffolding included questions that followed the initiate-respond-evaluate format (IRE) and open-ended questions in a whole-class setting. To a lesser degree, Mitch used scaffolds like graphic organizers and written questions to support students in individual argumentation.

Much like Mitch's direct instruction, the majority of his scaffolds for students were oral. For example, as Mitch taught the CER framework in his first unit, he used IRE questions to support students as they developed claims on the topic, "Is Water Wet?" The example below shows how Mitch used questioning as a scaffold for students to develop their claims in this unit:

Mitch: Ok, so, what's your reasoning?

Student: Because it sticks to your hand

Mitch: What, you've got pigs sticking to your hand?

Student: What?

Mitch: What is "it"?

Student: Water

Mitch: Ok, so restate your reasoning.

Student: The water sticks to your hand

Mitch: Why?

Student: Why? I don't know.

Mitch: Your reasoning has to use your evidence and your claim. All you're telling me is your claim. You said water sticks to your hand. That's your claim. Your evidence is your experiment. So tie it all together with your reasoning.

Student: I'll pass.

Mitch: You'll pass? Does anyone want to give him an idea of how he might connect his evidence to his claim?

In this example, Mitch questions the student to help him link his evidence to his reasons. The student, however, is unclear on how to do this. Mitch then broadened the question to other students for support. Mitch frequently used this type of questioning structure when students volunteered with the intention of helping them and the class understand how to develop claims, evidence, and reasoning.

Mitch also used written forms of scaffolding such as charts for students to copy into their notebooks, graphic organizers, and guiding questions to support students in argumentation. For example, he provided students with a chart to help them organize evidence and reasoning in the unit, "Human Impact on Climate Change." This unit was developed with the other biology teachers in this study, but Mitch adapted it for his own class.

Also, for the daily scientific articles students read, Mitch included guiding questions prompting them to critique the author's claim and evidence or to develop their own positions about the topic. For example, after reading an article about Greenland's thickening ice barrier, he asked students to "answer the question of what's happening with the ice? What's their evidence they use? And what was their reasoning for why this might be an issue? See if you can do that." While Mitch did not intend these readings as argumentation instruction, his use of the words evidence and reasoning gave students practice in identifying components of argumentation.

Feedback. Mitch also used feedback to instruct students in argumentation. Mitch relied solely on oral feedback with individual students and in whole class discussions. Mitch's feedback was intended for students to use immediately to fix the argument they were making at the time with less emphasis on transferring the feedback to different arguments. For example, for Mitch's daily scientific articles, he required students to check off their responses to the questions with him at the beginning of class. As Mitch looked over their written answers, he would either approve or ask students to adjust their answers if there were problems. For example, on one student's response, Mitch said, "You need to fix this. That's not even enough words. It says in this article—wrong. Is that really a reason? Because [my teacher] says so? That's not a really a reason." This response, while abrasive, provided feedback on the student's reasoning. The student revised his response before returning to Mitch with another answer. This process took a large portion of the class-time, especially when Mitch had to approve each students' response multiple times. Mitch mentioned during coaching sessions that this time allowed him to grade students' work during class and gave him some planning time during class because he had such limited time before and after school.

Mitch also used oral feedback as students worked independently. As students were collecting evidence about climate change, Mitch went around to the students and spoke quietly with them, "You've got your claim, evidence, and reasoning? What's your full claim? Who else is done? Raise your hand so that I can see what you've got." As students raised their hands, Mitch provided feedback, directing students to fix problems he saw or to confirm that they were correct. Students were expected to fix their arguments immediately in response to Mitch's suggestions before they submitted their assignments.

Finally, Mitch gave oral feedback to student volunteers as feedback for the whole class. He often rephrased what students said, adding in his view as he did so. For example, in his first unit, as he paraphrased a students' reasoning about water being wet, he said, “Okay. I think that works with reasoning.” Mitch’s feedback in this whole-class setting was also intended to help students to immediately revise the arguments based on the suggestions from Mitch. For example, after a student provided a claim, evidence, and reasoning for the unit, “Human Impact on Climate Change,” Mitch prompted students to add in scientific principles in their reasoning saying, “You kind of hit some of the points. Anybody else want to try? With greenhouse gases, all that kind of stuff?”

Mitch’s feedback was never written and always provided in impromptu contexts where he had little time to analyze or evaluate students’ responses. The two graphic organizers that Mitch had his students complete in the first two units were not returned to students with written feedback. Instead, Mitch relied on feedback while students were completing the assignment.

How Mitch’s Experiences and Beliefs Mapped Onto His Instructional Practices

The second research question asked how teachers’ experiences and beliefs related to the decisions they made about incorporating argumentation. For this question, I categorized the experiences that teachers described in their initial interviews and coaching sessions into two categories: teaching experience and argumentation experience. I also categorized their beliefs from the same sources into two categories: beliefs about science education and beliefs about scientific argumentation. For each section below, I examine how Mitch’s experiences and beliefs mapped onto his instructional practices. When comparing Mitch’s beliefs in his first interview to his last interview, both his definition of argumentation and the value he saw in using argumentation differed dramatically, so the last section addresses these shifts in beliefs.

Teaching Experience

In looking at teacher experience, I wanted to see what types of instructional practices teachers frequently used in their classrooms such as teacher-centered instruction, or instruction where the teacher makes sense of the content for the students (Granger et al., 2012) and student-centered instruction, or instruction where students construct skills and understanding with support or guidance from the teacher (Serin, 2018). Though Mitch had limited experience in the classroom, he was asked to describe the instructional strategies that he had used during his first year of teaching and that he anticipated using in the upcoming school year. Mitch had one year of experience teaching science. Based on this one year, Mitch described commonly using student-centered instruction, teacher-centered instruction, and disciplinary literacy. Figure 11 summarizes Mitch's teaching experiences that he reported in his initial interview.

Student-Centered. In describing his previous year of teaching, Mitch reported using student-centered instruction daily. Much of this instruction centered around having students "figure out" information. Though Mitch described much of his class as including instances where students "figure things out for themselves," Mitch's exact instructional strategies were less clear.

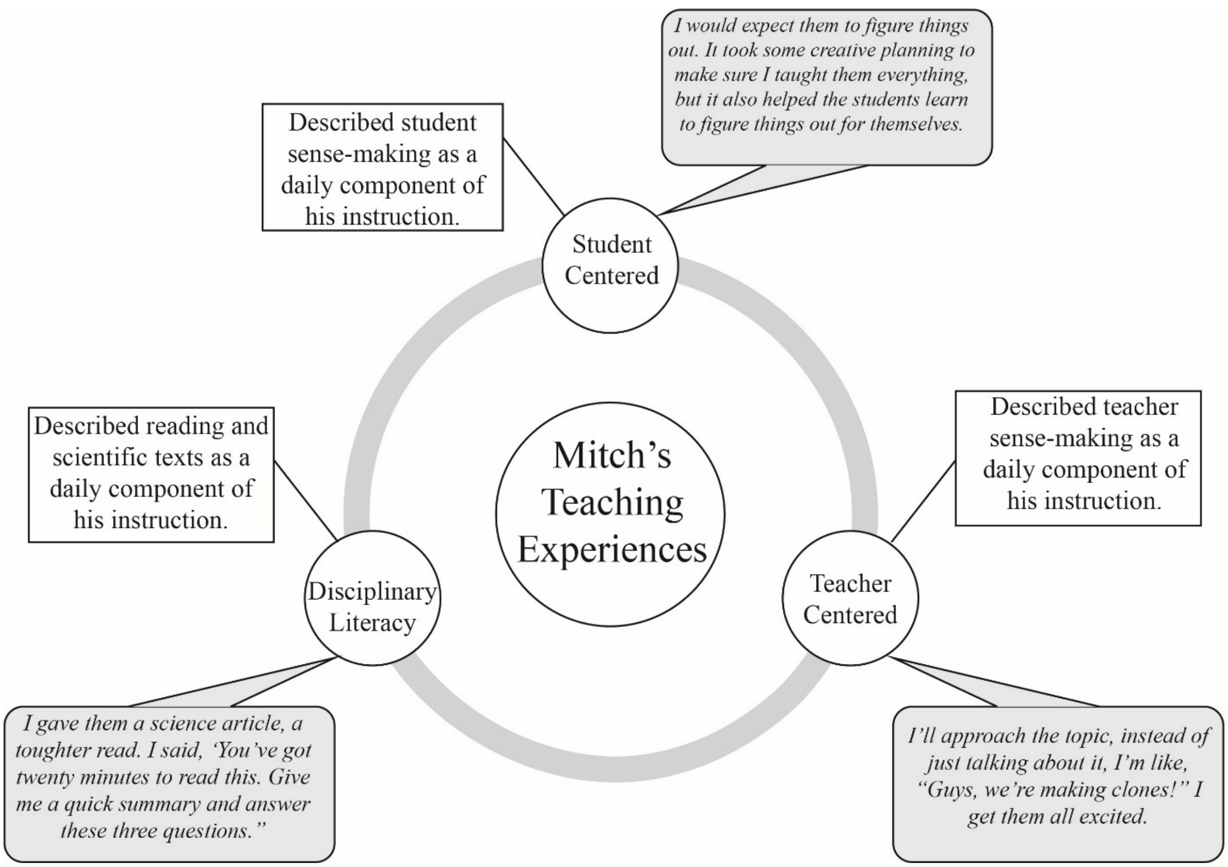
His own account of his class was chaotic and non-traditional. In describing his previous year of teaching, he said:

> The way I taught was very open and changing, and kind of a crazy environment. So, there was a whole lot that I would say or do, and students would be really confused. If they wanted to get it, they needed to figure it out. I don't know how I get it to work, but I do get it to work.

This explanation of Mitch's instruction emphasizes that students must make sense of science themselves to understand, but as Mitch noted, he was not sure of the methods he was using to support this in students. In further explaining this style of instruction, Mitch clarified that "I'm going to help them figure out everything, for sure… It took some creative planning to make sure I taught them everything." Mitch's clarification here indicates that he did try to offer support to students as they made sense of his content.

Figure 11

Summary of Mitch's Teaching Experiences



Mitch offered a more specific example of student-centered learning that he had used in the past when he described how he started his class each day. Mitch reported using a current scientific article at the beginning of class to help students engage in making sense of science, connecting science to their lives, and critically thinking about science.

> So, during those bell works and everything, I set the bar pretty high. ‘Hey if you don’t understand a word or how something works, you’re going to need to research and figure out how it works. If you can’t figure it out, you’re going to ask a partner. You’re going to figure it out together.’

Mitch noted that the most common thing about his instruction was its variability. He saw this working for him and his students because students were able to adapt and figure things out.

Mitch’s reliance on student-centered learning related to the way he chose to introduce argumentation to his class. For example, before defining his argument structure, Mitch asked students to attempt making a claim, providing evidence, and giving reasoning. After students had made several attempts, he provided a definition for students related to the examples they gave. Mitch’s oral argumentation unit about DNA also reflected his emphasis on having students figure things out. Though his debate was clearly structured, the instructions for students in forming their arguments was much more open ended. The students were directed to take different roles, but beyond that, they were left as a group to decide how to research and develop their argument.

Teacher-Centered. Mitch described some experience with using teacher-centered practices. Most of Mitch’s description of this focused on engaging the students and getting them excited about science. For example, he described introducing students to far-fetched ideas in his genetics class to get students excited about topics. For example, Mitch would shout things like, “Clones! Super powers!” to get students excited. Mitch also described using multiple examples, analogies, and stories to engage students with the content. Mitch also mentioned that he liked to use interactive activities to help students remember scientific concepts. For example, he mentioned an activity that he done with light waves where students threw candy at each other and equated that to the way light waves bounce off of other materials.

Though all of these examples were focused on getting students to interact with science, I labeled these experiences as teacher-centered because Mitch was making sense out of the examples, analogies, and stories for the students. Though Mitch's teacher-centered practices did not follow a traditional lecture style of teaching, Mitch offered the explanations for how each activity demonstrated an important concept.

Mitch's argument instruction incorporated limited teacher-centered practice. He often embedded teacher-centered instruction with student-centered instruction. For example, in asking students to try out argumentation in his first unit, he interjected his definition of high-quality arguments and definitions of the argument structure. Mitch's experience in getting students excited about topics through teacher-centered instruction reflects Mitch's choice of topics for argumentation. For example, his experience in using highly engaging and inciteful topics led him to use topics like "Is water wet?" to get students started on argumentation.

During his argument instruction, Mitch also adopted an incendiary teaching style to encourage disagreements among his students for the purpose of engagement. For example, he noted that he "almost had a brawl" in another class with his first period, encouraging his students to do the same thing. His choice of using a debate also reflects this interest in engagement and excitement. Mitch joked that his role during the debate was to "make sure nobody throws punches" during the debate. In both of these examples, Mitch highlighted a combative view of argumentation to foster enthusiasm in his students.

Disciplinary Literacy. Mitch reported having experience in using disciplinary literacy in his course. One thing that Mitch saw as an important learning foal for his students was having them read a scientific article every day to start his class. Mitch planned on providing students with articles that were published within "two weeks or a month," so that students could read about current issues in science. Mitch also had experience in supporting students in reading scientific studies instead of news articles reporting on the studies, but he mentioned that he wanted to improve his instruction to get students reading scientific studies sooner than he did last year. In describing his previous year using scientific articles he stated:

> Last year I think I had most of the class able to at least understand that scientific journal article. It was really long. I taught them to read that in ten minutes or less. But that took me all the way to the end of the year. I would like to get that first term of the year. You know, by January.

Mitch continued using scientific articles at the beginning of his class throughout the year. His initial description of his instruction emphasized comprehension of the articles in a short period of time. As Mitch continued to incorporate these articles into his course, he also incorporated questions that asked students to both identify the author's argument in the article as well as to evaluate their evidence and reasoning. As stated before, Mitch did not view these activities as argumentation instruction, but as he engaged students in other argumentation lessons, he also applied the terms and skills of argumentation into this established practice.

Argumentation Experience

Mitch described most of his argumentation experience as being outside of the science classroom. He remembered writing reports in his science classes but noted that these were mostly lab papers that were “almost like spitting out or regurgitating” what he was supposed to find. Mitch expressed personal interest in current science arguments dealing especially with socio-scientific issues such as genetics. “I’ll read like argumentative materials on like, hey, is this the best? I love genetics. Is this DNA manipulation the best way versus this?”

Outside of science, Mitch reported that he had experience in argumentation in his English courses. In these arguments, Mitch said, “That’s really fun and everything, and I can do really good, I guess. Manipulate the argument however I want. And I got really good at that.” In the initial interview, Mitch saw less value in this type of argument, though. “It feels more personal and more subjective.”

Mitch had some experience using argumentation in his genetics classes, though he had not tried it in his biology classes. Notably, Mitch initially saw the socio-scientific argumentation as non-scientific argumentation. “It’s not the kind… It’s like English arguments. Like they’re arguing over the ethics of gene editing and CRISPER and is it okay that a scientist just designed a baby, you know?”

Mitch’s experiences mapped onto the way he integrated argumentation into his course. Though he initially had students practice a scientific claim about the role of humans in climate change with a CER structure, a unit developed collaboratively with the other science teachers, he defaulted to the types of argument practices he had used in his genetics classes previously. He framed this argument as a battle where either side could win depending on their ability to defend their position and attack the opposing side. In this argumentation unit, Mitch assigned students to sides instead of having them choose the side they saw as the most defensible. In this case, Mitch was emphasizing argumentation as a way of manipulating the argument much in the same way he described arguments in English courses.

Mitch's instruction in this unit also showed his own expertise in subjective types of argumentation in contrast to scientific argumentation. Mitch provided students tips for improving their argumentation with an air of authority. For example, he advised students to attack each other's sources as one way of critiquing their arguments:

> Hey, you need to be able to defend your source. And so, if you want to attack somebody's source and they say cnn.com and quote somebody, most likely that's an opinion. And if you say, "Hey, that's just somebody else's opinion, I don't like your source". Then they lose the points.

In this example, Mitch presents himself as an expert in this type of argumentation in a different way than he did in his second unit about human impact on climate change. In that unit, while giving feedback for student reasoning, Mitch noted, "I think that works," and in another instance when a student struggled with adding in reasoning, Mitch responded, "Don't worry. I can't do it either." Mitch's lack of authority in this type of argumentation compared to socio-scientific arguments reflects his description of having limited experience in scientific arguments and more experience in what he initially described as arguments outside of science.

Beliefs About Science Education

Beliefs about the purpose of science education and the learning goals teachers have for students may affect their instructional practices (Bryan, 2012; Pimentel & McNeill, 2013). The teachers in this study were asked about their overall purposes and learning goals in their biology courses and their beliefs about the best instructional practices for biology and challenges. Mitch's beliefs about science education were generally focused on empowering students to be able to find, consume, and critically think about current science issues.

Mitch summed up his main instructional goal as literacy-focused. "My main learning goal is to get them able to read scientific studies," he said in the initial interview. Mitch mentioned multiple times that he really wanted students to be able to research and read science. He emphasized skill over content knowledge. For example, he compared the usability of content knowledge to skills:

> I think that they're never going to remember photosynthesis or uh, electron transport chain, or anything like that, but when they're voting or they're studying or going to be making decisions. If they take the time to read something and they have that ability they can actually use that.

Mitch did not see himself as encouraging students to go into the field of science, stating "most of them are not going to be biology majors and get their master's and stuff." Instead, he wanted students to "make educated decisions on voting. I think research is used in every facet of life." Both of these statements reflect Mitch's belief that the real value of science was to help students apply scientific thinking to real world situations. He saw little value in what he referred to as "regurgitation" of scientific facts.

Mitch's focus on transferrable skills over science content reflected his purpose in his final argumentation unit. In this unit, Mitch chose a topic that he saw as current and relevant to students' lives. He asked students to consider whether law enforcement should be able to use DNA in criminal investigations. Additionally, Mitch emphasized skills he saw as valuable beyond science topics such as researching on the internet and attending to the reliability of the sources students chose.

Beliefs About Scientific Argumentation

Beliefs about scientific argumentation can help researchers understand teacher practices (Bryan, 2012). While beliefs are often difficult to distinguish from knowledge (Pajares, 1992), I looked at several beliefs about scientific argumentation. First, I asked teachers about what they believed a high-quality argument was, what good argumentation looked like, and what the best instructional practices for argumentation were. Next, I asked teachers about their beliefs about the value of argumentation as a part of biology instruction. Finally, I asked teachers about the challenges and barriers they saw to teaching and doing scientific argumentation. See Appendices A and B for the interview protocols. The beliefs teachers had in these three categories were inferred from statements teachers made during interviews and coaching sessions. Additionally, I inferred beliefs from statements teachers made during observations of their instruction. Mitch's beliefs about scientific argumentation changed throughout the study, so I discuss these changes at the end of this section.

High-Quality Scientific Argumentation and Instruction. Mitch defined argumentation as "Trying to prove something is right, or trying to prove something. And then you're going to argue why that's fact." As an example of scientific argumentation, he described it as, "You go through this hypothesis, and you have proven or supported that this finding is for real." As Mitch defined argumentation, he often added "Maybe" or "That's my understanding" or "that's my interpretation." Mitch viewed himself as having a limited understanding of argumentation. He differentiated scientific argumentation from argumentation in his college English courses, stating, "In science… you have more cut and dry things. And of course, there's always greys, and there always will be. But you can test those, and you can argue, and you're arguing the means of the test. How did you come to your conclusion?"

Mitch's ideas for teaching argumentation focused on problems. He thought that students should consider real world problems and think about how science should help solve them. For example, he thought students could determine "the best scientific practice for doing land conservation. What's the best scientific approach to maximizing our food supply." He also noted that "giving them a world a problem, maybe even a [local] problem that can be solved with science" would be a good use of argumentation." This relates to his overall view of science instruction which was focusing on using scientific practices such as researching and evaluating scientific claims to help apply them to the world through voting.

Mitch's instruction, including his definitions for argumentation, did not always reflect his beliefs about the objectivity of scientific argumentation, or the importance of testing in developing arguments. Instead, Mitch used mostly scientific texts and internet searches as the sources for his students' evidence. Though Mitch described the components of CER for students in similar terms to his beliefs, he also commonly added in definitions that countered this view, such as emphasizing argumentation as a battle or a fight.

Value. Mitch saw value in incorporating argumentation into science classes, primarily as a way to help students develop solutions to real-world problems. When asked about the value he saw in using argumentation he said, "Who knows, maybe we'll have, maybe we'll be on YouTube or something. Tenth grader figures out a cure for something. I don't know." Though Mitch was partially joking in this response, his view about the potential for argumentation to help students use science to make changes in their local communities stands out. Like his beliefs about the purpose of science education, he saw argumentation as helping students apply science to their own lives.

Challenges and Barriers. Mitch did not mention any challenges he anticipated in his initial interviews, but during coaching sessions, Mitch mentioned his own lack of experience and understanding of argumentation as a concern. In these sessions, he often mentioned that he did not know what he was doing or asked for validation that he was understanding reasoning and evidence correctly. Additionally, Mitch noted his own lack of time for both preparation and evaluation. “I coach football, so I don’t have a lot of time,” he noted. He also mentioned that getting his master’s degree in health science as taking a lot of his time outside of class.

Mitch’s argumentation instruction reflected both of Mitch’s beliefs about challenges and barriers. First, his decision to rely on oral instruction including his direct instruction, scaffolding, and feedback allowed Mitch to reduce his planning time as well as his grading time. For example, Mitch opted to use oral feedback for students’ responses on their graphic organizers in his climate change unit. He gave this feedback as students worked during class rather than collecting their assignments and providing written feedback.

Mitch’s shift away from CER was also related to his own lack of confidence in evidence and reasoning. Because Mitch did not see himself as fully understanding scientific argumentation, he simplified the argumentation structure to defending an assigned position. In spite of these challenges, Mitch did not rely on the literacy coach to support his curriculum development. In part, Mitch’s limited time before and after school reduced the amount of collaborative time he could spend with a literacy coach or collaborate with other teachers. Mitch also repeatedly emphasized that he “wanted to figure it out on his own.” This may explain why many of Mitch did not always tell me about argumentation units he had planned.

Mitch’s Changes in Beliefs about Scientific Argumentation

Mitch’s understanding of scientific argumentation as well as his ideas for how to teach argument changed between the beginning interview and the ending interview. In Mitch’s case, he had a more negative view of argumentation in biology courses. He was also frustrated with some of his own lack of knowledge and the way that transferred to the students.

Mitch’s initial description of argumentation was to prove something and explain why it is fact. In his final interview, Mitch had multiple views about what argumentation was that were contradictory in some ways. First, Mitch conflated argumentation in science with arguments on “social media. You know, everyone argues about everything.” In terms of this understanding, Mitch noted, “I’m so jaded towards arguments and negativity. And negativity, generally, even in the best managed situation is a product, one of the primary products of arguing.” Mitch linked this to his experiences in the classroom. He said,

> When I was teaching the kids, you know the argumentative thing and we used “Is water wet,” as one of our baseline questions, just to kind of practice and stuff, Kids were legitimately getting angry at each other and going back and forth. Then the resentment, you know; I noticed some of the kids pushed them to saying, “Well, you know what? I’m going to defend my answer no matter what.” And then other kids, “I’m going to defend mine, and I’m going to find research to what I want.”

Much of this negativity was incited by Mitch's definition to the class. For example, in the observation of the unit mentioned above, Mitch had the students offer a definition of argumentation that included "a fight" which Mitch clarified as a "conflict or an issue." Additionally, Mitch framed this activity as well as a later activity as "winning" rather than reaching a factual consensus. In this debate, Mitch tallied points between two sides to decide who had won the argument.

In contrast, Mitch mentioned aspects of argumentation that are more closely aligned with scientific views of argumentation, but he offered this as an alternative to arguments because he conceptualized argumentation as a battle. In contrast to debating, he thought that students should engage in "open learning where the student is asking questions and asking their peers, and maybe they had a disagreement. Diving deep instead of trying to automatically spur disagreement." Mitch also emphasized the importance of teaching students to be open to alternative positions in order to reach consensus. For example, he said,

> Students should listen instead of arguing. Listen to the research and then 'Oh, this is my idea.' Instead of saying, 'Well, you're wrong because this and this,' saying, 'Okay, well here's what I found,' You know. Maybe more of a building up of each other instead of a debate.

This statement from Mitch indicates two things about his changing perception of argumentation. First, he had come to view argumentation as an oral debate or a fight between students. In his instruction, this is also how he had emphasized argumentation. Later on in the interview, as he discussed the writing he had students do, he repeatedly mentioned that "students weren't debating against each other," to discount written practices that incorporated claims, evidence, and reasoning (even when students were asked to critique the positions or evidences in an article).

Mitch's conceptualization of argumentation as a contentious debate in which one side was the winner, not because of the factuality of their claim, but because of their entrenchment, led him to question the usefulness of argumentation—at least that form of argumentation—in his classroom.

Mitch emphasized the importance of the right question in helping students engage in argumentation. He noted,

> A good biology teacher would find a really [good] question that's not been answered that has many different possible answers, you know. So, find one of those good questions to do research on and maybe have one per unit. Maybe five or six times you have a good little debate/discussion.

Mitch emphasized using questions that were not already answered by science for argumentation. "You know with global warming or something. Okay, we know that it's going on, so we can't really ask, is it going on." Mitch also mentioned that argumentation lessons take a lot of class time, especially at the beginning.

Another thing Mitch mentioned about teaching argumentation was the focus on the CER framework. He mentioned that having students differentiate between the three components was difficult. He noted that he thought the R should just be left out and students should just be asked to explain their thinking.

> I think that maybe we focused too much on trying to differentiate between the two. And instead, we should have just… These are high school students. It doesn't necessarily matter if they differentiate between the two because I can see that they have evidence.

Mitch developed this answer further by saying

> An English teacher that's really good at this, you'll look at the reasoning and how they interpret things. Cause I just don't have the knowledge. And it's very tricky trying to teach a student both things while they're learning something new.

Mitch's changing beliefs about best practices for argumentation and the value he saw in argumentation centered around both Mitch's limited experience in scientific argumentation as well as the unintended consequences of trying to increase engagement in argumentation through combative terms. Interestingly, Mitch's suggestions for improving argumentation instruction focused on many of the ideas he initially expressed about argumentation such as having students explore both sides of a problem to help them develop a solution. Additionally, Mitch also described his own approach to argumentation as, "I was determined to figure it out on my own," but mentioned at the end of the study that in teaching argumentation in the future he would, "I would probably allow—I would do more team-type teaching. I would need the support of somebody else who knows how the students were going to struggle."

Summary of Case 3: Mitch

Initially, Mitch saw argumentation as a valuable practice in science that could help students apply science to their lives and local communities. Mitch incorporated three argumentation units into his instruction. The findings for research question one showed that Mitch relied primarily on oral instruction to support his students through direct instruction, scaffolding, and feedback. Mitch's direct instruction of argumentation both defined arguments as including all parts of the CER framework as well as argumentation being a battle or a fight. Additionally, Mitch used direct instruction to emphasize skills he saw as important in argumentation such as attacking the opposing view and defending a position. Mitch's used a graphic organizer for scaffolding as well as questioning to support students in making arguments. Mitch provided feedback as students constructed arguments to help them revise and improve that argument.

Mitch's limited teaching experience reflected his argument practice. Mitch's self-described student-centered practices that required students to figure things out in a non-traditional classroom matched the way he initially introduced argumentation. Mitch's previous use of scientific texts to start his class each day also reflected argumentation skills such as identifying and critiquing existing arguments. Finally, Mitch's focus on teacher-centered instruction primarily for engagement echo the way Mitch introduced argumentation and the way his argumentation instruction developed over time.

Mitch's beliefs about science education were also apparent in his instructional choices. Mitch's beliefs about the purpose of science education reflected the topics he chose for his argumentation units, focusing on current issues that he viewed as impacting students' lives today. Mitch's beliefs about argumentation as he stated them in his initial interview did not consistently match up with the way Mitch defined argumentation. Mitch's experience in argumentation outside of science matched more closely with his description of argumentation as a battle that could be won by manipulation.

Mitch's definition of argumentation and the value he saw in using argumentation changed at the end of the study. Mitch saw argumentation as creating a negative atmosphere in his classroom. He also saw using argument as reinforcing entrenched views about science rather than arguments based on facts and logic. In thinking about how to teach argumentation, Mitch thought that the highly structured CER framework was often confusing for both him and his students. Instead, he emphasized the importance of having students develop ideas in more of collaborative way to reach consensus. Finally, Mitch recognized that collaborating with others to support his own limited knowledge of argumentation could be effective in improving argumentation instruction.

Case 4: Andrew

Andrew was in his 25th year of teaching at the beginning of this study, all of them in the same high school. Andrew had taught biology the majority of those years in addition to many electives including astronomy, plant science, greenhouse, and aquaculture. His degree was in ornamental horticulture, and he had worked in landscaping before earning his biology endorsement to teach high school.

Andrew noted that he had little experience in using scientific argumentation in his classroom, but he shared ideas for what he thought would work during our first collaborative group meeting. During part of the first semester, Andrew also had a student teacher, Carly, who collaborated on instruction in Andrew's biology course and taught some of the lessons. If Carly participated in any of the planning or instruction for the units listed below, I include her in the description.

Below I first focus on how Andrew integrated argumentation into his instruction including the types of argumentation units and instructional practices he used, when he incorporated the practices into his instruction, and his learning purpose for the argumentation units. Next, I address my second research question, looking at how Andrew's experiences and beliefs mapped onto his decisions about argumentation instruction. I specifically describe Andrew's beliefs about science education and scientific argumentation. Andrew's beliefs about argumentation became more developed by the end of the study, so I conclude Andrew's case with a description of his beliefs after incorporating argumentation into his class.

Andrew's Integration of Scientific Argumentation: How, When, and Why

The intention of the first research question was to look at the ways teachers incorporated argumentation into their classes. I developed codes to describe the instructional strategies the teachers used to engage students in argumentation, in other words, how the teacher integrated argumentation. The first section below looks at the design of each of Andrew's argument tasks such as how argumentation was defined for the students as well as other key features like the duration of the activity, the class groupings, and the type of data students were using for evidence. These results came from the transcripts of the observations, coaching sessions, and artifacts. The second section describes Andrew's specific instructional practices, when he used the practices, and why he used them.

Overview of Andrew's Instruction and Design of Argument Tasks

Andrew was the most limited in his use of scientific argumentation of all four teachers. He tried to maintain his traditional instruction as much as possible, so the argument tasks we collaborated on were often additions to his established lectures and general organizational plan. Though Andrew had many ideas about topics that would be good for argumentation, in his actual instruction, he simplified or truncated the argument activities we had planned.

Andrew's main argumentation unit took place during the first quarter in collaboration with his student teacher, Carly. This unit incorporated the CER framework, scientific text in the form of graphs, and formal written arguments. Andrew and Carly turned this activity into a multi-day activity when they felt that their students were not understanding the concepts of evidence and reasoning.

Besides that one formal argumentation unit, the other scientific arguments were informal activities focused on one or more argumentation skill, but not an entire argument. For example, while discussing GMOs, the students were asked to make an informal claim about whether GMOs should be legal or not. Some students volunteered to add in their reasoning, but all students were only asked to decide on a position. In contrast to this, students were asked to focus on gathering evidence in a unit about evolution. Andrew intended this unit to end with an argumentative essay using the evidence they had gathered, but because of school closures due to COVID-19, students only focused on gathering and sorting evidence.

All of the argumentation units used teacher lectures as a main source of data and reasoning. In two of the activities, students were asked to engage in argumentation individually. In two of the activities, students also engaged in argumentation as a whole class. The GMO argumentation unit used oral argumentation, but this was generally sharing their positions rather than engaging with each other in a group discussion. Table 13 shows the features of each argumentation unit Andrew used.

Table 13

Case 4: Features of Andrew's Argumentation Units

Argumentation units	Argument Structure	Style	Mode	Duration	Source of Data/ Reasoning	Class Grouping
Human Role in Climate Change	CER	Formal	Written	Multi-Day (2)	Teacher Lecture	Whole Class
					Scientific Text	Independent

Should GMOs be Legal?	Claim	Informal	Oral	Mini-lesson	Teacher Lecture	Whole Class
Evolution*	Evidence	Informal	Written	Multi-day (3)	Teacher Lecture	Independent

*Due to COVID-19 school closures in March 2020, this unit was incomplete

Andrew's main purpose for scientific argumentation was variation and engagement. In coaching discussions, he brought up possible topics for us to use for argumentation that would get students more engaged. Many of his ideas were based on previous experiences with students. For example, in discussing a possible topic related to macromolecules, he described how he had a student who was vegan. This student argued that meat was not necessary in the diet. He mentioned that this student was very passionate and engaged in this topic. "I've had some that haven't been so informed, but she is great. She's also done her homework and she is not the stereotypical vegan who is anemic and pale and 83 pounds. She has done her homework and she eats correctly."

Most of Andrew's suggestions for argument topics focused on issues with some level of controversy including GMOs, evolution, and the safety of eating meat. He also referred specifically to the controversy in suggesting these topics. "Ecosystems—that's a highly debated topic in the U.S. right now… Genetics, also some very controversial topics." With his purpose of engagement, Andrew often chose socio-scientific topics or presented them in a socio-scientific way (such as whether GMOs should be regulated by the government).

Andrew's Instructional Practices for Scientific Argumentation

Andrew used few instructional practices to support students' argumentation. His instruction tended to focus on science content rather than argumentation. Andrew wanted argumentation to follow the lectures of scientific concepts that he traditionally did, which blended argumentation into his existing practice. He incorporated graphic organizers and provided feedback on the students' arguments. Table 14 shows the instructional practices incorporated into each of Andrew's argumentation units.

Table 14

Case 4: Andrew's Instructional Practices by Unit

Argumentation unit	Direct Instruction	Scaffolds	Feedback
Human Role in Climate Change	Defined CER	Graphic Organizer Questions	Oral Annotations
Should GMOs be Legal?		Questions	
Evolution*		Graphic Organizer	

*Due to COVID-19 school closures in March 2020, this unit was incomplete

Direct Instruction of Scientific Argumentation. Andrew and Carly presented argumentation in their first unit using the CRE framework. They presented the definition of each of these topics within the context of their first argument related to the role humans play in climate change. Evidence was presented as the information depicted in a series of graphs. Reasoning was presented as scientific principles that helped explain and interpret the information. Claims were presented as a clear answer to the question.

In subsequent lessons, the terms CRE were only referenced again on handouts provided to the students. Andrew referred to evidence frequently in argumentation lessons. He used other terms such as “theory” to describe a claim, and he used the term “proof” to describe reasoning to the students. For example, in one lesson about evolution, Andrew used an analogy about court systems to explain evidence and “proof” to students. After having the students observe evidence from fossils, images of skeletons, and images of embryo development, Andrew asked:

> So, does this prove anything? No. It’s evidence. You take four or five evidences together. It supported the theory. You go to a murder trial. Here’s one piece of evidence. The prosecution says he did it. Defense says he didn’t do it. This is the proof. It’s the same piece of evidence, it’s just different based on how you look at it. So, this is not the proof. It’s the evidence.

In this example, Andrew was emphasizing that evidence by itself does not prove the theory, but rather the interpretation of the evidence is what links the evidence to the claim. In accordance with his purpose, Andrew did not discuss that one position could be better supported than another, leaving students to view argumentation much as Andrew viewed it, an opinion.

Aside from the unit, “Human Role in Climate Change,” Andrew did not provide direct instruction for before asking students to engage in argumentation. The direct instruction for this first unit took place at the beginning of the unit to support students in structuring their arguments.

Scaffolds. Andrew used graphic organizers in two different units to help students with argumentation. In the first unit, the graphic organizer was the same one the Julie used for her students following the CER argument structure. Additionally, Andrew used a graphic organizer (See Figure 12) to help students gather evidence for them to use on argumentative essay at the end of the quarter. This graphic organizer was intended to be used as the students listened to Andrew’s lectures over the course of the unit.

Figure 12

Andrew's Graphic Organizer for Evolution

Biological Diversity and Evolutionary Change

Instructions: ***Each day*** *you discuss biological diversity and Evolutionary Change, you will fill in* ***one row*** *of this graphic organizer.*

Date	**Principles of Evolution** *Summarize the concepts of evolution. Make sure to include key terms (like natural selection).*	**Evidence** *What evidence have scientists used to support the principles of evolution you discussed today? For example: geological or fossil records, DNA, experiments, observations*	**Evaluate** *Do you think the evidence supports the principle? Do we need more evidence?*

Andrew's scaffolds were primarily used during class lectures. His main purpose in using these argumentation scaffolds was to support students' understanding of the science content.

Feedback. Andrew and Carly used oral feedback at the beginning of the year with their first argumentation practice. They had students describe evidence they noticed in the graphs as well as provide reasoning explaining and interpreting the data. They primarily confirmed the students' answers or redirected the students if their quality was low. This took the form of IRE questioning primarily.

Additionally, Carly led a whole-group discussion evaluating student examples as a form of feedback. After having students fill in a graphic organizer and practice writing a paragraph addressing the question, "To what extent are human actions responsible for temperature change?" Carly and Andrew selected a variety of examples from student papers. Carly specifically emphasized reasoning in her feedback. During a coaching session, she stated, "We were mainly focusing on them getting the right concept and idea. Because they just, they weren't getting it. And once I did that, I started getting, I did get multiple correct evidence and reasoning, and they started getting better." This was the only instance that Andrew had students practice argumentation after providing feedback.

Andrew and I also collaborated on a rubric that was intended to be used on an essay for the evolution unit. Andrew opted not to have students write the essay when students were working remotely, and so he did not use the rubric to provide feedback to the students.

How Andrew's Experiences and Beliefs Mapped Onto His Instructional Practices

In addition to how teachers incorporated argumentation into their classes, I also wanted to see how their experiences and beliefs related to their instructional decisions and practices. For my second research question, I categorized teacher experiences that they described in their initial interviews and coaching sessions into argumentation and teaching experience. I categorized beliefs into two categories: beliefs about science education and beliefs about scientific argumentation. For each section below, I examine how Andrew's experiences and beliefs mapped onto his instructional practices. Andrew's beliefs about argumentation became more developed in the final interview, so the final section addresses how Andrew's beliefs changed after incorporating argumentation into his biology class.

Teaching Experience

In looking at teacher experience, I wanted to see what types of instructional practices teachers frequently used in their classrooms such as teacher-centered instruction, or instruction where the teacher makes sense of the content for the students (Granger et al., 2012) and student-centered instruction, or instruction where students construct skills and understandings with support or guidance for the teacher (Serin, 2018). Teachers were asked to describe common instructional practices they used in in their classroom already to establish both their experiences and the classroom community the teachers created for the students.

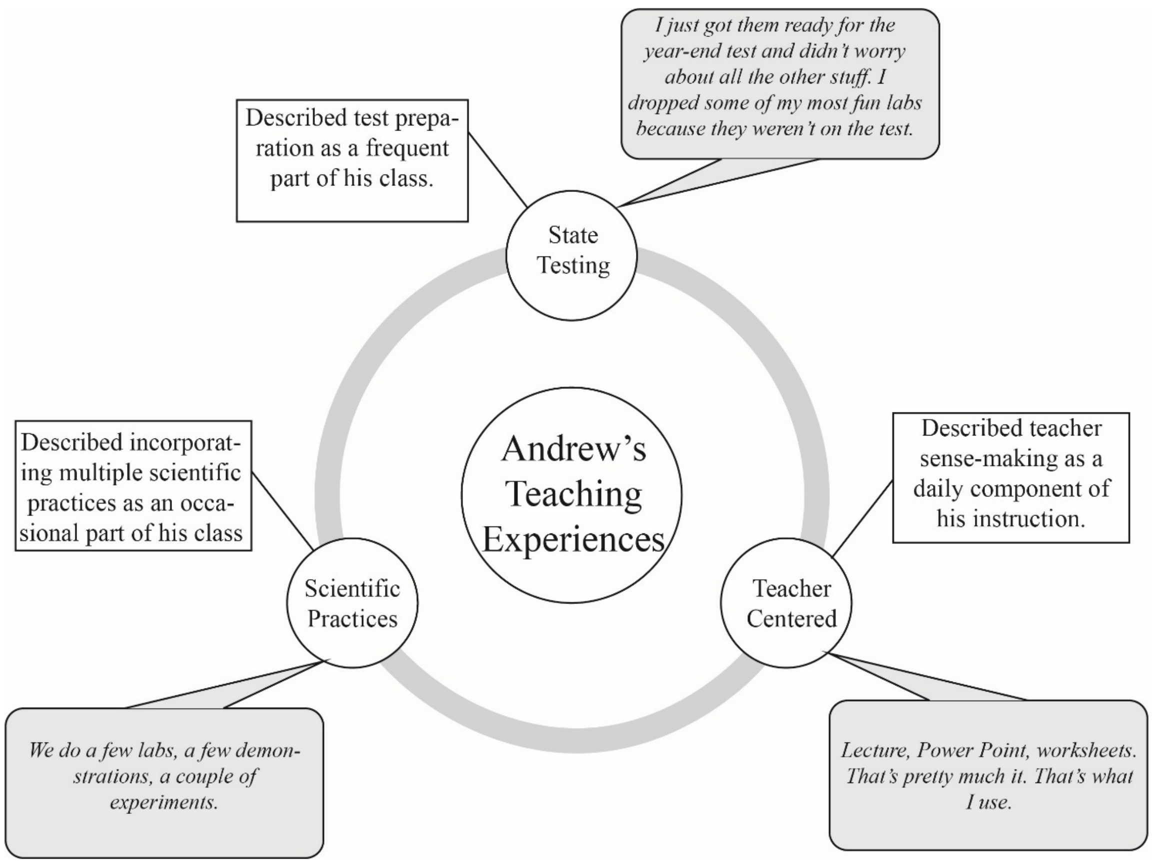
Andrew was starting his 25th years of teaching. He had taught biology and a variety of elective courses at the same high school for all of his teaching years. He had the most experience teaching biology, but he also taught plant science, astronomy, greenhouse, aquaculture, and soil science. He became a teacher after working for several years as a professional landscaper and a “nursery man.” Since his degree was in ornamental horticulture, many of the electives he taught were related to his previous experiences in landscaping. Andrew earned an endorsement in biology prior to teaching. He had no other degrees. Andrew reported commonly using teacher-centered instruction, test preparation, and scientific practices. Figure 13 summarizes Andrew’s self-reported teaching experiences and provides statements from his initial interview.

Teacher-Centered. Andrew’s established classroom practices were mostly teacher-centered with Andrew interpreting and describing the key concepts of his course. His classroom was set up to facilitate this with all of his tables in single rows facing the front. Andrew described his daily lessons as lectures using PowerPoint slides or using transparencies on his over-head projector. These lessons were conducted using direct instruction with some whole-class discussion. Students were encouraged to take notes from his slides but were not required to. Andrew’s slides usually contained bulleted lists highlighting the key ideas. He also included images and examples on his slides.

Andrew’s instruction for argumentation was also primarily teacher-centered and embedded into his class lectures. When he integrated argumentation into his course, he did it following direct instruction through lectures and presentation slides. For example, when Andrew and I had planned incorporating argumentation about regulations for genetically modified food, Andrew primarily presented the evidence to his students, emphasizing the relative safety of genetically modified food.

Figure 13

Summary of Andrew's Teaching Experiences



Aside from the unit Andrew completed with Carly about climate change, most of the activities he had students engage in were short, taking little time away from direct instruction of content. Additionally, he favored argumentation practices that prioritized gathering scientific evidence, but often did not have students use that evidence to develop a claim or reason through that evidence.

Test Preparation. Andrew's main reason for not having more student-centered activities was largely related to the importance he put on state testing which has been mentioned previously. In the past two years and in the upcoming year, however, the test in Andrew's state for biology had been replaced with a general science assessment. When Andrew was asked if he planned on incorporating his engaging labs or focusing on student knowledge, he said, "I haven't put a lot of them back in."

When Andrew added argumentation activities into his class, they were not assessed in the same way that Andrew assessed content knowledge. He continued using multiple choice tests for his content and added argumentation primarily as a way to vary his instruction before returning to his lecture.

Scientific Practices. Andrew also mentioned that he had students complete labs and watch demonstrations. Though these two activities could be student-centered, Andrew set them up as teacher-centered. He often demonstrated how to make cheese for his classes while they watched. They had the option of tasting the cheese but had no other involvement in the process.

Andrew noted that students occasionally worked in groups to research and present information to the class. Andrew also noted that what his common practices in the classroom may not be the best way to teach science. He mentioned that he dropped "fun labs," indicating that these labs may have been more engaging for students.

Argumentation Experience

Andrew did not remember using any form of argumentation in learning science. Describing his science education, he said, "I had to write research papers and present information. That's not really argumentation. It's not two different sides of the same idea. I haven't done very much of it at all."

Andrew also said he had no experience using argumentation in any of his science courses. He mentioned that some of the standards on the core asked students to develop arguments, but he had not done them primarily because they were not tested. Andrew noted that most of his teaching experience had focused on variations of end-of-level tests. Andrew described this as:

> I don't think I've really used a lot of argumentation. Up until two years ago, we always had a year-end test. End-of-level test, SAGE test. And everything that wasn't tested on the test, I didn't teach. Argumentation was one of those. So, I just got them ready for the test and didn't worry about all of the other stuff. I dropped some of my most fun labs because they weren't on the test.

Beliefs About Science Education

Beliefs about the purpose of science education and the learning goals teachers have for students may affect their instructional practices (Bryan, 2012). The teachers in this study were asked about their overall purposes and learning goals in their biology courses, their beliefs about the best instructional practices and their beliefs about challenges in teaching biology. The following sections describe Andrew's beliefs in each of the categories and how those beliefs mapped onto his argumentation practices.

Purpose of Biology. Andrew described his main learning goal for students as "they have to learn the curriculum. There are five main topics: ecosystem, chemistry of living cells, genetics, evolution, and organs and organ systems." He described his assessments of this content as 70 questions for each unit consisting of multiple-choice questions and true/false questions.

In some conversations during individual coaching sessions, Andrew did mention the importance of critical thinking skills, especially dealing with controversial science topics. For example, in discussing a lesson on genetics, he said,

> They could be voting on legislation dealing with all of this. They'll be the ones that are voting on this kind of stuff, so you ought to have background in it. I mean, not being an expert, but you should know a little bit about what goes on. And the process and not be—like they're scared. So many scare tactics that go along with genetic modification that people freak out about.

In his lessons in class, Andrew also brought these ideas up with students, asking them to think about the application of some of the science, especially with genetics, on their lives and their future. He himself viewed science primarily as mastery of scientific content.

Instruction. Andrew's beliefs about science instruction reflect his experiences in the classroom. He had a content-centered view of biology instruction and referred to the topics in the state standards, but omitted any practices mentioned in the same standards. When asked about instructional practices, Andrew generally named content that he presented to the students.

Additionally, Andrew had some conflicting views about his own instruction and good science instruction. He said, "If I was really to do it [science instruction] correctly, I would have them give me their opinion and their feedback on what they know on a topic. I would have them present what they know, what they learn, and what they can prove." This statement also indicates that Andrew believed he should have more student-centered practices that accounted for students' own background knowledge and encouraged more sense-making to be done by the students.

Challenges. Andrew mentioned student ability as a challenge in teaching biology. "Some of them are AP Biology ready and some of them don't have a clue what's going on." He also mentioned later that students come with a variety of reading levels which makes argumentation based on a text difficult. "Some of them are very good at picking out important parts and some are not." Andrew did see this as something that he could address as a teacher, following up with, "So, there's some work to be done there."

Beliefs About Scientific Argumentation

Researchers (Duschl, 2008; Henderson et al., 2018; Osborne et al., 2004) have noted that because scientific argumentation was not a part of most high school science teacher's own learning, they may not understand scientific argumentation themselves and may struggle incorporating it into their classroom. Additionally, teachers who do not see argumentation as valuable in science education may truncate or simplify argumentation lessons (McNeill et al., 2018). To understand how the teachers' beliefs about argumentation mapped onto their argument instruction, the teachers were asked to define argumentation and to describe possible ways they believed argumentation should be incorporated into their class. Additionally, the teachers were asked what value, if any, they saw for using argumentation in biology. Finally, teachers were asked to describe any challenges or barriers they saw to incorporating argumentation at the outset of the study. See Appendix A for the initial interview protocol.

Andrew's beliefs about argumentation countered some of his beliefs and experiences in science education. I first discuss this in terms of his beliefs about what counts as high-quality arguments and instruction followed by his beliefs about the value and challenges of incorporating argumentation into his class.

High-Quality Scientific Argumentation and Instruction. Andrew had a general conception of scientific argumentation centered mostly around controversy. He did not differentiate scientific arguments from a broader sense of argumentation. Unlike the other teachers, Andrew did not focus on argumentation using the CRE framework. Andrew's beliefs and understanding of argumentation showed the most change between the first and last interview, especially in what argumentation instruction should look like and how often it should be used.

Andrew defined argumentation as "presenting your opinion, your version of things." He believed that arguments could be presented in any format. He noted that science "cannot be opinionated, it has to be facts." Andrew also presented argumentation to his students as various interpretations of the same evidence or the same facts. There seemed to be some conflict in his mind between science, which was fact, and arguments, which were opinions. He also used "Pro and Con" to describe arguments, emphasizing the two-sided nature of argumentation.

Andrew's ideas for argumentation focused on what he saw as highly controversial topics. He repeatedly used the phrase "controversial" when suggesting topics for his course. "Evolution is highly volatile," for example or, "Ecosystems, that's a highly debated topic in the U.S. right now."

Beyond suggesting topics, Andrew did not have man ideas for teaching scientific argumentation. He noted that many "facts are wrong" in dealing with controversial science topics, "so their opinion is kind of skewed." This suggests that students should look at the quality of the evidence supporting argumentation, but Andrew did not suggest any methods for how to do this.

Value. Andrew saw some value in using argumentation in his course, but his beliefs about the value of argumentation were limited in the initial interview. He noted that argumentation "probably should" have a role in his course as an assessment tool, showing "what they learn." Andrew did mention that he believed argumentation may not support students in understanding scientific concepts or take away from their ability to do well on tests.

Challenges and Barriers. Andrew's lack of experience in teaching argumentation also made him view argumentation as too time consuming in a variety of ways. He described using argumentation time consuming for students, "It takes time to teach them new skills." He also noted, "Learning how to do it and teaching kids how to it: it's a learning curve for both sides." Additionally, Andrew mentioned that because he had not used argumentation in the past, he needed to find good materials to support students which was time consuming. He specifically mentioned "for me to go through and find three good articles, it takes hours and hours." Instead of spending time developing new methods to teach argumentation or find high quality materials to use for evidence gathering, Andrew preferred to fit short argumentation activities into his existing practices such as having students take a position on a question at the end of a lecture, or informally offer their opinions about a topic in a whole class discussion.

Andrew's Changes in Beliefs about Scientific Argumentation

Andrew developed both his understanding of argumentation and his ideas for instruction the most out of all the teachers between his first and final interviews in spite of his limited implementation of argumentation in his course throughout the year. At the end of the study, he framed argumentation as a literacy practice related to consuming and evaluating information from scientific articles. This contrasted his earlier definition of scientific argumentation as controversial or volatile debates about science. In his final interview, he also saw scientific argumentation as a valuable practice that should be incorporated more frequently in the biology course, suggesting that other teachers (not Andrew, since he retired at the end of the year) should practice argumentation at least twice a quarter.

Andrew still defined argumentation as an "opinion," but also added "a presentation of your learning." He stated that he believed argumentation was about the same as he thought, but he had learned more about it. "[Students] do research, they present the finding, the research, the opinion, and the basis for what I think." Specifically, he had a better understanding of what skills students needed to engage in argumentation. He mentioned that students needed "to be able to infer." He mentioned this specifically for gathering evidence. "They need to be able to read something and then pick out the major points of that."

Andrew also saw argumentation as a key component to learning science at the end of the year. "It's a learning tool. It's a means to an end. It's not the end. If they can understand and synthesize articles about genetic engineering" to develop a claim, "then they understand the concept of that."

Andrew also described argumentation as requiring students to critically evaluate information.

> Students have to be able to figure out, is this a valid paper or not and what they are really trying to say… Where's the facts? What do the facts actually say? Students have to be able to figure out what has actually been researched and what is just hype and what is opinion.

While Andrew still viewed argumentation mostly in terms of socio-scientific arguments, he offered more ideas about what students needed to do in order to make high-quality arguments.

Andrew also had many more ideas about how to teach argumentation in a biology course. He tied these instructional activities to disciplinary literacy as well. He thought that students should practice identifying the support and position developed in one article before comparing contrasting positions in multiple articles. “Here’s two articles. Compare and contrast the two. And then you say, okay, here are five articles and then they present a paper.” Andrew thought that students should be introduced to argumentation slowly and looking at the argument in a single article would be best before proceeding to multiple positions. Andrew did not suggest having students develop their own explanations but focused mostly on evaluating published arguments.

Andrew also suggested using feedback on varying levels of student work. After having students identify the author’s argument and support, he suggested:

> Put some on the overhead and say here’s one student’s essay. Have the class critique it. Have them do that three or four different times so that they can see good student work, and [what] needs to be improved on student work.

This suggestion reflects one activity that Andrew’s student teacher used during the year when students struggled on their first scientific explanation. Andrew believed that argumentation would require more reading and so it would take more time from the class, but that it would be valuable. Reflecting on his teaching ability, he thought that using argumentation was a learning curve for him. “I can’t teach it if I don’t know it. The only way I can learn it is by doing it.” He mentioned this “learning curve” repeatedly as a challenge to using argumentation in the classroom.

Summary of Case 3: Andrew

Andrew believed that argumentation could be a valuable part of science instruction, but his overall beliefs about science education and his experiences preparing students for year-end tests limited the amount of argumentation Andrew actually incorporated into his instruction. The findings for research question one show that Andrew's main incorporation of argumentation occurred when he co-taught with his student teacher, Carly. In this unit, Andrew and Carly used direct instruction, scaffolding, and feedback to support students' argumentation. Aside from that unit, Andrew primarily used scaffolding to help students gather evidence or develop claims informally and incorporated argumentation to reinforce science content.

Andrew's experiences rather than his beliefs informed his instructional practices most clearly. Andrew was reluctant to change any of his instruction in practice, even though he collaborated and planned ways to add argumentation to his class during coaching sessions. When Andrew did add the argument activities into his lesson, he generally simplified them so that they became a part of his lectures rather than emphasizing them as a distinct scientific practice.

Even with this limited argument instruction, Andrew's beliefs and understanding of argumentation developed throughout the course of the study. Primarily, Andrew described the value of argumentation as essential in helping students develop critical thinking skills about current science topics. Andrew also had multiple suggestions about how to teach argumentation in the future in contrast to his limited ideas in the first interview. He emphasized the importance of both scaffolding and feedback in supporting argumentation. Andrew continued to view time as a major challenge in using argumentation. He mentioned both the time for giving feedback and grading students' arguments as well as the time argumentation would take away from science content.

Cross-Case Analysis

In the individual cases above, I examined how each teacher incorporated argumentation into their instruction and how their beliefs and experiences related to their decisions. In this cross-case analysis, I compared the teachers' instructional choices including features about the units they incorporated and their instructional practices. In discussing these patterns, I emphasize both the similarities and differences within the pattern. Often, the differences in the teachers' experiences and beliefs mapped onto the differences in their instructional choices, including when they incorporated strategies and why. This cross-case analysis concludes by briefly comparing the development or changes in beliefs about high-quality argumentation and instruction.

Comparison of How Teachers Incorporated Scientific Argumentation

The teachers in this study all incorporated argumentation multiple times throughout three quarters, though some teachers relied on more informal arguments or shorter argument lessons. Table 15 provides a comparison of the features of each teachers' argumentation units. This table shows the features that the teachers incorporated in at least one unit throughout the year.

Table 15

Comparison of Argumentation Unit Features

	Structure	Duration	Style	Mode	Class Grouping	Data Source

	CER	CER+	Mini-Lesson	Single Day	Multi-day	Formal Written	Inform. Written	Formal Oral	Informal Oral	Whole Class	Small Group	Ind.	Science text	Teacher lecture	Int. Search
Julie	x	x	x	x	x	x	x		x	x	x	x	x	x	x
Jordan	x		x			x				x	x	x	x		
Mitch	x	x	x	x	x		x	x	x	x		x	x	x	x
Andrew	x		x		x	x			x	x		x	x	x	

Most of the teachers, with the exception of Jordan who was teaching AP Biology curriculum, collaborated at the beginning of the year on the unit, "Human Impact on Climate Change." Beyond this unit, however, the teachers developed their own argumentation units for the rest of the year, working with me as a literacy coach. All of the teachers used the general CER structure to define argumentation for their students in at least one unit. Additionally, all of the teachers incorporated direct instruction and at least one type of scaffolding and feedback as they incorporated argumentation into their units. Table 16 provides a comparison of the types of instructional practices that each teacher used at least once.

Table 16

Comparison of Instructional Practices

	Direct Instruction			Scaffolding				Feedback		
	Defined CER	Identified CER	Counter-claims	Graphic Org.	Questioning	Example	Notebook	Annotation	Oral	Rubric
Julie	x	x	x	x	x	x	x	x	x	x
Jordan	x	x		x	x			x	x	
Mitch	x			x	x	x			x	
Andrew (Carly)	x			x	x				x	

Argument Structure

Some notable similarities among the teachers were their use of explicit definitions and graphic organizers for the argument structure CER. The CER framework for argumentation was adopted by the whole group during their first collaborative coaching session, so all teachers used this structure at least once in their instruction. However, three teachers expanded the CER or moved away from this structure by the end of third quarter indicating that the CER structure may not fit all of their needs for developing student argumentation.

All of the teachers defined high-quality arguments as having a claim that answers a question, evidence that includes facts and data, and reasoning that connects the evidence to the claim at the beginning of their units. Jordan maintained this structure for all of his argumentation units throughout the three quarters. Jordan's purpose for his argument activities was to support students' in passing the AP exam. His consistency reflects a more rote instructional model where Jordan taught and discussed students' arguments, then provided them with continual practice in the same types of questions as test preparation.

Julie's use of the CER expanded to include a counterclaim in the second quarter. Additionally, she expanded the final argumentative essay to follow a structure that included a thesis statement and background information before students presented their positions and addressed a counterclaim. Julie's expansion of the CER framework was based on her understanding of scientific argumentation as a comparison of two explanations. Julie viewed the CER structure as a foundational practice for students in writing explanations before they moved into a comparison of those two explanations. Her argumentative essay was also used as an assessment of student learning throughout the unit. While she wanted them to support an argument with evidence and reasoning, she also wanted students to establish their understanding of the topic before they moved into an argument. The structure she provided to students combined her view of scientific essays with that of an argumentative essay, such as shifting from using the claim to using thesis, and outlining the content that students should explain before they developed their arguments. Julie's expansion of the CER structure in both cases was an attempt to support students in what Julie viewed as more authentic scientific practices.

Mitch used the CER structure during two lessons before shifting to a different structure for his oral argumentation unit about genetics. In explaining the oral debate, Mitch focused on defining and explaining how students should attack the other side and how they should defend their own positions. He included explanations on how to critique sources, how to concede one point while emphasizing another, and how to maintain the position throughout the argument. One important reason for Mitch's shift was his own limited understanding of the CER structure for scientific argumentation. Mitch mentioned his limitations both with his students while he was presenting the structure as well as during his coaching sessions and interviews. Mitch moved away from this structure in the third quarter and relied instead on argumentation that fit his view of argumentation as combative.

Finally, Andrew also moved away from the CER structure in the second and third quarters of his class. Andrew's shift reflects his reluctance at spending the time to have students engage extensively in argumentation. He also wanted to maintain as much of his previous instruction as possible, so his arguments shifted to informal questions where students were asked to apply their understanding of the content in order to answer a question. In teaching argumentation, Andrew also tended to argue a position for the students, rather than have them develop their own arguments.

The CER framework provided all of the teachers with an entry point into argumentation. They all used graphic organizers tied to this same structure to support students' understanding of arguments, and the CER gave the students and teachers some terminology to discuss argumentation. The shift away from CER in the case of Mitch and Andrew indicates that simply providing teachers with a structure may not be enough support for them to integrate scientific argumentation consistently over time. In the case of Mitch, his own definition of argumentation did not fit into CER and so he reported struggling with it as a structure for students' arguments.

Data and Reasoning Sources

Another important similarity among the teachers' argumentation units was the reliance of scientific texts and lectures as the primary source of evidence and reasoning. None of the teachers incorporated data from student observations or student-designed investigations. Even though all teachers shared this same omission, the reason for focusing primarily on text-based sources of evidence differed among all of the teachers.

In the case of Jordan, his focus on test preparation for the AP exam led him to choose sources that reflected what students would see on this exam. Because students would primarily be asked to interpret information from texts, Jordan focused his argumentation activities around scientific texts such as case studies. Additionally, Jordan's use of labs in his previous teaching experience had been primarily to reinforce content that he had already taught them. This experience led Jordan to view labs as less of an investigational tool and more of another way to emphasize scientific content.

Similarly, in the case of Andrew, his own experience in test preparation reflected his most common instructional practice of directly presenting scientific content to students. His experience in using scientific practices like models and labs were also primarily confirmation of his instruction. Both Jordan and Andrew had over a decade of experience in teaching science in order to help students pass a multiple-choice test at the end of the year. This focus on memorization in both of their prior teaching experiences may explain their reluctance to have students gather evidence beyond texts or lectures to support their arguments.

Neither Mitch nor Julie described test preparation in their own experiences of teaching science. As newer teachers, both of them had started teaching in this high school after state mandated testing had been discontinued. Unlike Julie, however, Mitch also did not mention having experience in using other scientific practices in his classroom. Mitch's lack of experience in having students gather evidence from observations or complete any type of lab likely led him to focus on internet searches and scientific texts. Additionally, Mitch mentioned time as a major challenge to implementing argumentation. Many of Mitch's decisions in incorporating argumentation were based on time-saving factors such as providing students with oral feedback during class. Having students conduct investigations would require more advanced planning than instructing students to find information online.

Julie, however, did have experience in using scientific practices in her class, and she did not address time as a major challenge in teaching argumentation. Surprisingly, Julie also was the only teacher who had experience with scientific arguments in realistic science settings. Julie's beliefs about high-quality argumentation, however, were centered on formal school arguments that were clearly structured for students. Her interpretation of school argumentation, then, was based on texts rather than scientific investigations.

In all of the cases above, the embedded PD with a literacy coach likely reinforced the teachers' use of texts as their main source of evidence for their students' arguments. Without an expertise in science, I, as the literacy coach, was also more comfortable in supporting teachers' use of texts for argumentation.

Experiences and Beliefs. In all cases, the teachers' experiences or beliefs about argumentation and science education connected to how they integrated argumentation into their courses. Primarily, teachers' experiences connected to their instructional decisions more than their beliefs, especially if their beliefs contradicted their teaching experiences. For example, in the case of both Andrew and Jordan, their beliefs about how they should teach science often differed from what their teaching experiences. Their experience in teacher-centered instruction and test preparation for most of their teaching careers reflected their integration of argumentation as a reinforcement of their teacher-centered instruction.

In Julie's case, her teaching experience informed both her beliefs about argumentation and the ways she incorporated argumentation into her instruction. For example, Julie's limited experience in teaching argumentation made her believe that argumentation instruction should be highly structured for students. As a result, her direct instruction and feedback emphasized the structure of arguments over the quality of each argument component. Many of Julie's scaffolds also emphasized her belief that arguments should be structured. She provided graphic organizers and outlines to help ensure students incorporated claims, evidence, and reasoning in all of their arguments.

Mitch's case serves as a contrast to the three teachers above. Mitch's beliefs about argumentation did not match up with the way he presented arguments to his students. With limited experience teaching and no experience with argumentation as a student, Mitch's argument instruction reflected his experience with argumentation in what he referred to as an English context rather than reflecting his beliefs about scientific argumentation. Like the other teachers, though, Mitch's experiences seemed to inform his argumentation more than his initial beliefs about argumentation.

Changes in Beliefs About Argumentation

Argumentation includes two processes: construction and critique (Ford, 2008a; Osborne et al., 2016). In this study, all four teachers saw argumentation in terms of construction. All teachers believed that evidence for scientific argumentation should come from established scientific facts. Beyond these shared views, the teachers differed in their views of argumentation. Mitch and Andrew also saw argumentation as combative or adversarial. Andrew used words like "controversial," "highly-debated," and "volatile," at the beginning of the study when he was asked to define argumentation. In presenting argumentation to his students, Mitch used combative words like "fight" and referred to arguments as having a winner. In contrast, Julie and Jordan emphasized that scientific argumentation should not be combative, but should include the critique or evaluation of multiple claims. Julie noted that scientific arguments should be a comparison of two or more explanations in order to find which one was most valid. Similarly, Jordan emphasized that scientific argumentation centered around two fairly valid explanations.

In the cases of Julie, Jordan, and Andrew, their views of scientific argumentation in their final interviews were more clearly articulated both in terms of how they defined it as well as their view of what high-quality argumentation and instruction should look like. For Andrew, his initial view of scientific argumentation as controversial or volatile changed to a more literacy-based view of argumentation in which students should look at and evaluated existing claims. Julie and Andrew both added the importance of evaluating multiple claims. Andrew believed that students should have practice looking at differing texts about the same topic to evaluate each of the existing arguments. Julie mentioned critique as a key skill to develop in students and thought having them critique their own arguments as peers' arguments could develop this important skill. Jordan emphasized the importance of clearly articulating and persuading the audience in his discussion of argumentation. In all three of these cases, the teachers saw scientific argumentation as a more complex process and were able to more clearly identify key features that should make up a high-quality argument.

Mitch's beliefs about scientific argumentation continued to center around the idea of argumentation as oppositional, but because he saw argumentation as a battle, he changed his views about the value of argumentation in science. Mitch saw argumentation as leading to a general negative environment and to entrenched positions rather than as a practice for engaging students in the process of evaluating and collaborating claims based on scientific evidence.

All teachers, including Mitch, also developed more specific ideas for how to teach argumentation. Initially, Mitch, Andrew, and Jordan emphasized topics they could use for argumentation as their main ideas about instructional strategies. By the end of the study, they all named specific strategies including additional scaffolding, sources of evidence, and methods of feedback that they would use to support the students. It is important to note that while Mitch had ideas about how to get students to listen and evaluate evidence and reasoning, he primarily viewed these instructional strategies as a substitute for scientific argumentation.

Summary of Findings

This research study analyzed data from four different biology teachers over the course of three quarters to identify how teachers with little to no experience incorporated argumentation into their instruction. Observations, coaching sessions, and teacher artifacts indicated that even though all teachers implemented some teaching strategies supported by research for argumentation, the features of their argumentation units, purposes for their instructional strategies, and contexts of their instructional strategies differed. The teachers' experiences and beliefs provided insights into some of these differences.

Although all four teachers used direct instruction, scaffolding, and feedback, each teacher used these strategies for a different purpose. Julie's argumentation units and instructional strategies emphasized the importance of the argument structure, or the importance of including all components of the structure. Most of Julie's direct instruction, scaffolding, and feedback supported her main learning goal of ensuring that students included a claim, evidence, and reasoning. In the second case study, Jordan's main purpose for argumentation was to prepare them for the AP exam at the end of the year. With this in mind, Jordan's direct instruction and feedback focused on the quality of each component within the CER framework. In the third case study, Mitch's learning goals for students in his first two argumentation units were to support students in understanding the structure of an argument. In his final unit, Mitch's learning goal centered around critiquing and defending positions. The first unit as well as Mitch's last unit was also intended to increase engagement of students through argumentation. Mitch's scaffolding and feedback in his first two units provided support for students in the argument structure. In all three units, Mitch used direct instruction to define argumentation as a battle or a fight to increase engagement. Finally, Andrew's argumentation practices were embedded into his content lessons and intended to support their knowledge of science concepts. These differences in learning goals mapped onto the way the teachers used the instructional strategies.

For all four teachers, their previous experiences played an important role in how they incorporated argumentation, including their learning goals for their students. For Julie and Mitch, their experience with student-centered instruction carried over to their argumentation instruction. In Julie's case, her student-centered instruction was clearly scaffolded and purposefully blended with teacher-centered instruction. In Mitch's case, his student-centered argumentation activities reflected a less-structured approach with less support for students, but an emphasis on student engagement. In these classes, both the teachers and students were comfortable with the student-centered nature of scientific argumentation.

In addition to teaching experience, Mitch's experience with argumentation outside of science informed the way he taught argumentation. In contrast to this, Julie's prior experience with scientific argumentation in authentic contexts did not inform her argumentation instruction. Julie relied on her teaching experiences to drive her argumentation instruction rather than her science experiences outside of the classroom.

These two teachers were the only teachers who reported having experience in creating argumentation.

In the case of Jordan and Andrew, their many years of teacher-centered instruction also carried over to their instruction of argumentation. In Jordan's case, he noted that students struggled to interpret and develop their own claims, instead, they often simply restated the information from Jordan's lectures or from accompanying texts with. Jordan's description of students' argumentation parallels Jordan's expectations for his other instructional practices including labs and quizzes. Jordan's argumentation activities were used to reinforce information from his lectures in addition to preparing students for the AP exam. In contrast to Jordan, Andrew's instruction beyond the argumentation unit he taught with his student-teacher tended to simplify and truncate the activities he had planned with the literacy coach so that he could continue his traditional teacher-centered instruction.

The teachers' beliefs about science education and scientific argumentation did not clearly map onto their argumentation instruction in the same way that their experiences did. In the case of Mitch, Jordan, and Andrew, their beliefs about what science education and high-quality argumentation should look like, including their definitions of argumentation, contradicted their instructional practices. In these cases, their experience played a more dominant role in their decisions. Julie was the exception to this. Her beliefs about both science education and argumentation instruction linked closely with her instructional strategies, including when and why she used these strategies in argumentation.

In spite of the differences among the teachers' integration of argumentation, all of them developed more complex understandings of argumentation, including more nuanced ideas of how to teach argumentation. This was true even in the two cases of Andrew, whose integration of argumentation was especially limited, and Mitch, who ultimately believed argumentation created a negative teaching environment.

Below, I list the main findings from this study that will be discussed in chapter five.

- Over the course of the study, all teachers incorporated some features of argumentation units and strategies that research has shown to lead to positive student outcomes in research on scientific argumentation, but most teachers did not incorporate critiquing or investigation in their argumentation units.
- Teachers' purposes for using argumentation informed the way the teachers set up argumentation for students and how they used instructional strategies.
- Scientific argumentation requires students to do some sense-making, so teachers with experience using student-centered instruction transitioned into argumentation more easily than teachers who primarily used teacher-centered instruction.
- When teachers' beliefs did not align with their prior teaching experiences, teachers' experiences informed their instruction more than their beliefs.
- Regardless of the amount of argumentation teachers incorporated into their course, all teachers developed a more complex and nuanced view of scientific argumentation by the end of the study.

Chapter V

Discussion

Despite the benefits of scientific argumentation for student learning in science, teachers do not often engage their students in argumentation (Drew et al., 2017; Osborne et al., 2004). Researchers have mentioned several reasons for this including teachers' lack of experience with argumentation (Henderson et al., 2018), the complex literacy demands of argumentation (Litman & Greenleaf, 2017), and teachers' views of science education as sharing established facts of science rather than engaging students in the language and practices of science (Duschl, 2008; Lemke, 1990; Osborne et al., 2004). This study was designed to compare four teachers with little experience in argumentation as they incorporated argumentation into their biology classes with the support of a disciplinary literacy coach.

This multiple case study of four high school biology teachers was designed to address the following research questions:

1. How, when, and why do high school biology teachers integrate scientific argumentation into their instruction in the context of disciplinary literacy coaching?

2. How do each teacher's experiences and beliefs map onto their decisions related to integrating scientific argumentation?

The data collected for this study included multiple observations of teacher instruction, transcripts of coaching sessions, interviews at the beginning and end of the study, and teaching artifacts. These data sources were collected over the course of three quarters to allow for in depth analysis of teacher practices and beliefs.

This chapter first summarizes the key findings that emerged from the data analysis and discusses the significance of them in terms of scientific argumentation before offering recommendations for education and future research.

Instructional Strategies for Supporting Argumentation

Scientific argumentation is a complex process that requires specific skills including competency in complex literacy skills (Goldman et al., 2016) and scientific practices (Faize et al., 2018). To support students in developing these essential skills for successfully engaging in argumentation, multiple instructional strategies have been mentioned in research of scientific argumentation (Dawson & Carson, 2020; Simon et al., 2006) including a clear argument structure (Jonassen & Kim, 2010), facilitating productive oral discussions (Christodoulou & Osborne, 2014; Erduran, 2006; González-Howard & McNeil, 2020; Simon et al., 2006), and developing foundational skills such as critiquing and evaluating evidence (Ford, 2008b). All of the teachers in this study incorporated some effective instructional strategies to support their students, but each teacher also omitted important features or instructional strategies in their units. After discussing the theoretical framework in this study, I discuss the instructional strategies in depth below.

Communities of Practice and Disciplinary Literacy Coaching

The disciplinary literacy coaching model used in this study centers around the idea that the teachers and the coach were engaged in creating a new community of practice focused on teaching students scientific argumentation. This type of coaching does not situate the literacy coach as expert and the teacher as a novice (Lave & Wenger, 1991), but instead it acknowledges the content expertise of the teacher and the literacy expertise of the teacher. In this study, I supported teachers' existing instruction, collaborated with them on developing curriculum, and reflected on teacher instruction. Much of this discussion was jointly led by the teachers and me as the literacy coach. As a literacy coach with a background in language arts and history, aspects of my membership in these communities contributed to the new community of practice developed through coaching. Similarly, the teachers' membership in other communities played an important role in how we developed meaning, practice, community, and identity (Wenger, 1998).

Teachers' understanding of biology and their existing practices served as a starting point for all of the coaching sessions I had with teachers. To encourage teachers to change their practices, I prompted the teachers to suggest topics, data sources, and activities that fit into the science content they were currently teaching. As a disciplinary literacy coach, I collaborated with teachers on these materials, often asking questions based on my lack of expertise to help teachers think about the best ways to support student learning (Wilder, 2014). As a literacy coach, I suggested instructional strategies, made modifications on handouts or created requested materials with input from the teachers, but focused the coaching around teachers' needs and requests.

Direct Instruction of Argument Structure

Explicitly defining a structure of argumentation for students has been linked to learning benefits in multiple studies (Dawson & Carson, 2017; Jonassen & Kim, 2010; McNeill et al. 2006; Simon et al., 2006). Many of these studies used a general argument structure based off of Toulmin's (1958) argument pattern (TAP) (Dawson & Carson, 2020; Giri & Paily, 2020; McNeill, 2009) that have improved students' construction of argumentation, critical thinking, and understanding of argumentation. Simon et al. (2006) suggested that argument structures based on TAP give teachers the language to talk about argumentation with students. In this study, all of the teacher explicitly defined argument in terms of claims, evidence, and reasoning (CER) at least once. Two of the four teachers maintained this structure for each of their argumentation units. Only one teacher used this argument structure for all of his argumentation units, while one teacher adapted the CER for her final unit. The other two teachers moved away from this structure entirely in their final argumentation units.

This is an important distinction among the teachers. Studies looking at argument structures have not examined when or why teachers may introduce a new structure into their units. In fact, Simon et al. (2006) found in their study that teachers' "initial approach to implementing argumentation was not fundamentally altered, but rather, refined or extended over the year" (p. 256). Julie's extension of CER to include a counterclaim as well as her extension of the CER into a broader essay structure aligns with this finding as does Jordan's continued use of CER. The other two teachers, however, moved away from this framework entirely. This shift away from CER in both cases was primarily related to the disconnect between their beliefs about effective science instruction. Additionally, in Mitch's case, his abandonment of CER may have been related to his own limited understanding of argumentation in terms of this structure.

Some researchers (e.g., Dawson & Carson, 2020) have mentioned the potential drawbacks of using TAP in scientific argumentation. They argue that general structural frameworks can overemphasize the inclusion of each component of the argument, but not on the quality of these components (Sampson & Clark, 2008). Julie came to see her instruction in a similar way, reflecting that she often emphasized the structure of the argument and the importance to include all three components of argumentation without discussing the quality of each component.

Scaffolding Oral and Written Argumentation

Scaffolds are important to support students in the complex task of argumentation (Andriessen & Baker, 2014; Sandoval & Millwood, 2005). Structural scaffolds such as graphic organizers or writing frames have contributed to an increase in the components students included in their arguments (Dawson & Carson, 2020). Additionally, a combination of scaffolds contributed to both oral and written arguments in Giri and Pail's (2020) study of high school students. In the same vein scaffolds such as open-ended questions (McNeill & Pimentel, 2010), prompting students to provide justification (Ryu & Sandoval, 2012), and providing sentence starters to support students' reasoning (Mercer et al., 2004) improved students' oral argumentation.

In the current study, all four teachers incorporated structural scaffolds at least once in their argumentation units. Reflecting McNeill et al.'s (2006) study, Jordan and Julie used structural scaffolds in the beginning of the year but faded these supports out for their later argument practices. Three of the teachers used questioning as scaffolding for students including open-ended questions, but this was infrequent. Teachers used this type of scaffolding when developing supporting skills for argumentation, such as evaluating evidence, but not when students were developing complete arguments.

Sources of Evidence for Scientific Argumentation

Though research in scientific argument has focused on hands-on contexts of argumentation, scientific argumentation is often based on reading and evaluating scientific texts or data gathered by other people (Goldman et al., 2016). Simon et al. (2006) included providing evidence to students such as in a scientific text was a common strategy that teachers successfully used in argumentation. The teachers in the current study all used scientific texts as the main source of evidence for their students' arguments. These included data from graphs and tables as well as information embedded in an article or study. Julie and Jordan relied on texts most frequently for their students' arguments. Mitch provided students with scientific texts as well as directed students to search the internet for information. Andrew used one scientific text for the first argumentation unit, but had students rely on information from his lectures for the rest of his units.

Missing Instructional Strategies

Though all of the teachers included multiple strategies that are effective in supporting students' argumentation, all of the teachers left out important strategies. Because the disciplinary literacy coaching emphasized collaboration, the teachers and I worked together on lessons suggested by them, the science experts, supporting them with suggestions on curriculum materials and prompting them to reflect on their instruction to improve teaching in upcoming lessons. If teachers did not suggest strategies such as using investigation for argumentation, we focused on the activities that they did suggest. The patterns of strategies that teachers collectively left out contribute to our understanding of how teachers new to argumentation integrate it into their class.

Even though scientific argumentation is often centered on reading and gathering evidence from published studies, another important element of scientific argumentation is having students develop questions and design investigations to help them develop arguments that answer the question (Faize et al., 2018). Sampson et al. (2010) have advocated for an argument framework where students design and carry out an experiment before they debate or discuss their claims as a class. Similarly, Ford (2012) argued that student sense-making of science was better when they engaged in constructing and critiquing methods of investigation as a part of developing arguments.

The teachers in this study only used scientific texts, omitting investigations through experiments or observations.

Another important skill essential to argumentation is the ability to critique arguments, evidence, and methods (Ford, 2008b; González-Howard & McNeil, 2019; González-Howard & McNeil, 2020; Osborne, 2010). Two of the teachers, Andrew and Jordan, did not incorporate critiquing as a feature in any of their argumentation units. Although Jordan included one activity where students evaluated student arguments, the focus on this evaluation was in improving how students wrote their arguments instead of a critique of the soundness of the overall argument. These two teachers' instruction reflect the research that shows teachers often fail to prompt students in critiquing others' arguments (Christodoulou & Osborne, 2014) or omit opportunities of critique at all (Macpherson, 2016).

In contrast to Jordan and Andrew, Julie and Mitch included critiquing arguments as a feature of one of their argumentation units. Julie used scaffolding to prompt students to critically question each other's claims in small groups while Mitch centered his final argumentation unit around critiquing the opposing side. Most of Mitch's direct instruction in this final unit included explicit instructions for critiquing the other side. Both of these teachers had reported experience in student-centered instruction outside of argumentation while the other two teachers did not. Ford (2012) described teachers initially struggling to get their students to engage in critique because the students' expectations of teacher-directed instruction. Similarly, researchers have noted the importance of having a classroom environment that allows for student-to-student discussion prior to having students engage in argumentation (Berland, 2011; Driver et al., 2000; Gilles & Buck, 2019; Kilinc et al. 2017; Pimentel & McNeill, 2013). This distinction between teachers who incorporated critiquing and those who did not indicates the importance of teachers' experience as well as their established classroom practices.

Summary of Instructional Strategies

Even though some of the strategies the teachers incorporated into their study were limited, the use of explicit definitions with a clear structure, scaffolding to support the teachers' learning goals, and scientific texts as sources of evidence show that in the context of literacy coaching, the teachers' instruction of argumentation matched research-based recommendations for argumentation instruction. However, teachers also omitted important instructional strategies to support student learning. This finding reflects research (McNeill & Knight, 2013; Wang & Buck, 2016) showing PD models can support teachers in the increase of at least one effective argumentation strategy, but because of the complexity of both doing and teaching argumentation, research on PD suggests that teachers need substantial time to practice, reflect, and improve their instruction (Christodoulou & Osborne, 2014; Osborne et al., 2013).

Teacher Purposes for Argumentation

Echoing research (González-Howard & McNeil, 2019; Katsh-Singer et al., 2016; McNeill, 2009; Wang & Buck, 2016) that found teachers' learning goals impacted their instruction, the teachers' learning goals in the current study informed the way they set up their arguments, and how and when they used direct instruction, scaffolding and feedback. In spite of collaboration early in the year to set common learning goals for teaching argumentation, all of the teachers established distinct learning goals for their argumentation units. These differences in learning goals explain some of the different ways teachers used instructional strategies and changes to their instruction throughout the year.

For example, Andrew's argumentation goals were focused less on supporting students' argumentation skills than as a way to support science concepts. Andrew's case reflects multiple other case studies in which teachers' who saw less value in argumentation than science concepts simplified or truncated their argumentation instruction (McNeill et el., 2018, Wang & Buck, 2016). In contrast, Mitch's goal of engagement made him frame argumentation as a battle to increase student participation. Though this goal was largely unconscious (Squire et al., 2003), it caused students to view argumentation as a competition (Berland, 2011), which made them reluctant to consider opposing views or change their positions, a consequence that led Mitch to ultimately question the value of argumentation at the end of the study.

Other learning goals, such as focusing on the structure of argumentation without acknowledging the quality of each component (Sampson & Clark, 2008) led Julie to focus her scaffolding and feedback specifically on the inclusion of certain components.

Similarly, Jordan's focus on test preparation informed both the length of his argumentation units (McNeill et al., 2018) and the way he defined high-quality argumentation for his students.

The disparate purposes in four teachers who all collaborated at the beginning of the study and worked with the same disciplinary literacy coach for the duration of the study highlights the multiple ways teachers envision argumentation working in their classroom. Learning goals that are especially entrenched in teachers to the point that they may not be conscious of them may lead to argumentation instruction that runs counter to the scientific practice of argumentation. Attending to these learning goals as teachers incorporate argumentation into their classes is important in helping teachers see the value of scientific argumentation and engaging in effective practices to support their students.

Student-Centered and Teacher-Centered Experience

The teachers described their prior experience teaching science and the common practices in their classrooms. One important distinction between the teachers was their experience in using student-centered instruction (instruction that supports students in making-sense of the science) and teacher-centered instruction (instruction where the teacher makes sense of science). High school science teachers traditionally have used teacher-centered practices to, "reveal, demonstrate, and reinforce" scientific concepts (Duschl, 2008, p. 269). In this study, three of the teachers stated that they used teacher-centered instruction through PowerPoint presentations and short labs or activities to reinforce their lectures. For Jordan and Andrew, this was the only type of instruction they reported using.

Teachers who favor teacher-centered instruction have struggled to incorporate argumentation into their courses which may be related to the fact that scientific argumentation requires students to make sense of science as they develop arguments (Christodoulou & Osborne, 2014; Ford, 2012; McNeill et al., 2018; Osborne et al., 2013; Wang & Buck, 2016). In this study, Andrew's incorporation of argumentation was especially limited after his student-teacher left. He continued to present himself as the authority (Wang & Buck, 2016) during planned argument lessons. In one lesson Andrew planned with the literacy coach, Andrew presented his argument about genetically modified foods and only asked for input from students in the last five minutes of class. Jordan used argumentation frequently, but he turned argumentation practice into a test preparation activity where students used argumentation to reinforce their understanding of science and practice written responses for the AP exam. In both cases, Andrew and Jordan's established teacher-centered practices continued to dominate how they taught argumentation.

Researchers (Berland, 2011; Berland & Reiser, 2011; Squire et al., 2003) also suggest that teachers' established practices in their classroom may affect how students engage in the unit. Squire at al. (2003) found that "the existing classroom rules, expectations and norms… appeared to drive much of the activity" as teachers incorporated a new curricular unit. This was also true for Jordan and Andrew. One main concern Jordan mentioned in coaching sessions during the study was that his students were treating argumentation as a regurgitation activity. In other words, they were simply rephrasing information from accompanying texts instead of interpreting the information to support a claim. Andrew's students were also reluctant to use handouts I prepared as the literacy coach to help them interpret and sort information as Andrew presented it to them. Students in both of these classes struggled to engage in student-centered practices that may be related to the established teacher-centered instruction that both teachers used.

As a disciplinary literacy coach, I worked with Jordan to support him in student-centered practices. I modeled leading students in a student-centered evaluation of sample arguments for Jordan. Jordan used the same types of open-ended questions and small group discussions as I did when he taught the same lesson with another class, indicating teachers with a background of teacher-centered instruction can develop student-centered practices to support students' argumentation skills (Zaccarelli, et al., 2018).

In contrast to these two teachers, Julie and Mitch reported having experience with student-centered practices. Julie reported shifting from teacher-centered to student-centered instruction multiple times during each class period and Mitch reported using little teacher-centered practice. Even though both teachers reported student-centered instruction, their description of what they had students do differed widely. Mitch, for example, described his instruction as primarily requiring students to make sense of science through unstructured and sometimes chaotic activities. Mitch equated his instruction to "throwing students into the deep end" and believing that they would rise to the challenge. In contrast to this type of student-centered instruction, Julie relied on much more structured activities. Julie scheduled table talks where students discussed questions, explained their understanding of concepts, or worked with manipulatives such as popsicle sticks to make-sense of what was happening. Julie embedded these activities within her teacher-centered instruction so that she could redirect students when they made mistakes or needed more support.

Like Jordan and Andrew, both Julie and Mitch's argumentation instruction largely reflected their student-centered practices (Squire et al., 2003) and differed from each other based on these established classroom practices (Berland & Reiser, 2011). In both cases, however, students engaged in these argumentation activities as the teachers expected. Students in Julie's class shifted easily to small group discussions about their claims and evidence. Similarly, Julie's students were comfortable when Julie withheld her view about DNA editing and encouraged students to figure things out based on the evidence they had.

The difference in the way teachers incorporated argumentation was largely based on their teaching experiences and the established practices in their classrooms. Even Mitch, who had only taught one year prior to this study, reflected his previous teaching experience. The findings in this study add to the research that recognizes a lack of experience with student-centered instruction is a barrier to incorporating scientific argumentation. In a limited way, Jordan was able to incorporate some student-centered instruction into his course in response to literacy coaching, but these practices did not transfer to other instances in his instruction.

Although research has primarily focused on problems with transitioning teachers from teacher-centered instruction to student-centered, this study also highlights that the way teachers use student-centered instruction may affect how teachers frame scientific argumentation. For example, Mitch's unstructured student-centered instruction led to combative forms of argumentation, even with Mitch himself. Mitch reflected on this as a problem in his final interview noting that students were using faulty evidence in their arguments but refused to listen to critiques about this or consider opposing claims as potentially better than their own.

Teacher Beliefs

Teacher beliefs about students, best practices for their subject, their own abilities, and even beliefs about what they are teaching all play a role in the choices teachers make in both designing and enacting their curriculum (Berland, 2011; Pimentel & McNeill, 2013; Sengul et al., 2020; Zohar, 2007). I use the term beliefs in this study to refer to teachers' beliefs about the nature of science education, including their views about best practices for teaching biology as well as their dominant goals for students in their courses. In addition to teachers' views of science education, beliefs in this case also refers to teachers' understandings about what counts as high quality argumentation in their field and what value the teachers' attribute to scientific argumentation as a classroom instructional practice.

Research (Bryan, 2012; Richardson, 1996, Sengul et al., 2020; Zohar, 2007) has linked science teachers' beliefs to their instructional practices. Specifically in scientific argumentation, researchers (Pimentel & McNeill, 2013; Wang & Buck, 2016) have found that teachers beliefs about science may impact the value they see in argumentation and subsequently the way they teach it and how much time they use for it. Other research, however, has noted an incongruous relationship between teachers' beliefs and their practices (Bryan, 2012). For two teachers in this study, their espoused beliefs, "what we say, but not necessarily what we do" (Bryan, p. 479), differed from their self-described teaching practices and the way they incorporated scientific argumentation into their class.

Jordan and Andrew both described ideal teaching practices as something separate from what they did before and after the study, saying, if they did it right, they would include more hands-on activities, and opportunities for students to discover scientific principles. Additionally, both Jordan and Andrew described important student outcomes that contradicted their instructional practices such as critical thinking. Both of these teachers' actual instruction reflected what they both described as pressure to prepare students for a high-stakes test at the end of the year. Their experience in test preparation informed their instruction of argumentation much more than their beliefs about what science education should be.

In a different way, Mitch's beliefs about argumentation countered his instructional practices. Mitch's initial beliefs about argumentation specifically focused on the importance of facts and objective reasoning. He contrasted scientific arguments from arguments in a language arts classroom as having more value because scientific arguments did not allow for manipulation of the evidence. Mitch's description of argumentation, however, countered this belief. In analyzing this difference, Mitch's experience also seemed to play more of a role in his actual practices than his espoused beliefs which may have been related to his limited experience with scientific argumentation. As a novice teacher, Mitch defaulted to the argumentation experience he had, namely his experience in non-scientific argumentation.

In these three cases, the importance of teachers' experiences over their beliefs highlights the importance of supporting teachers in both instructional experience and experience developing strong scientific arguments themselves. Another key component to all three of these cases is also the amount of teaching they had done. Mitch was a novice teacher and did not have much teaching experience to rely on. This matches studies (Kilinc et al, 2017; Simmons et al., 1999) about novice teachers' beliefs contrasting their practices. Andrew and Jordan, however, were experienced teachers, each with over 15 years of experience. Unlike Mitch whose lack of teaching experience may have limited his ability to enact his beliefs in the classroom, Andrew and Jordan's reported pressure to teach to a test for most of their teaching experience had established ingrained practices that they struggled to break away from in spite of their beliefs.

Julie's case contrasts these three cases above. Julie's belief about her goals for science education and her beliefs about argumentation matched up both with how she reported her teaching experiences and how she incorporated argumentation into her instruction. In fact, Julie's beliefs were informed by her prior teaching experiences (Bryan, 2012). Julie's emphasis on the importance of structure in engaging in scientific argumentation reflected both her instructional practices and her one previous attempt at using argumentation. If any incongruity existed in Julie's beliefs and experiences, it was with her experiences engaging in authentic science argumentation and her beliefs and enactments of school argumentation. Julie's decision to rely solely on scientific texts and not engage students in designing investigations to develop arguments may reflect this incongruity.

My expectation as the researcher in this study was that teachers' beliefs would align with both their experiences and the way they incorporated argumentation. For three teachers, this was not the case. Understanding how to support teachers in moving their established practices towards their beliefs about good science instruction may be important in professional development (PD) for experienced teachers where pressures from their schools, districts, and states have led them to rely on practices that do not align with their beliefs about both argumentation and science education. Additionally, as in the case of Julie, some teachers' views of science argumentation in the classroom may be distinct from the types of argumentation scientists engage in (Kang & Wallace, 2004; MacPherson, 2016). This may impact both how teachers engage in argumentation instruction and the value they place on integrating argumentation instruction into their classroom.

Finally, all of the teachers' beliefs about the best practices for argumentation tended to be vague at the beginning of the study and tended to focus on possible topics rather than practices. This limited understanding of teaching argumentation may offer some explanation for why teachers' experiences played more of a role in their argumentation instruction. Collectively, this multiple case study indicates the need for more research in understanding how teachers' beliefs and experiences interact and inform the way they teach scientific argumentation.

Changes in Beliefs about Argumentation

Teachers' understanding of argumentation has been linked to teachers' ability to support students' argumentation (McNeill et al., 2018; Zohar, 2007). Scientific argumentation may be simply defined as a justified or supported claim, but effective scientific argumentation must also align with the epistemological practices of the scientific community (Ford, 2008a; Sampson & Clark, 2008; Sandoval & Millwood, 2005; Walker et al., 2016). Teachers' beliefs about scientific argumentation may prioritize certain components of argumentation over others, or, due to both lack of training or experience, may substitute features of everyday argumentation, such as an adversarial battle for key features of scientific argumentation.

Three of the teachers' beliefs about the key features in scientific argumentation developed beyond their definitions at the beginning of the study, and became more aligned with scientific argumentation as described in the literature. Researchers (Ford, 2008a, Osborne et al., 2016, Sampson et al., 2010) have emphasized the importance of critique as an important part of scientific argumentation. In the cases of both Julie and Andrew, their views of scientific argumentation incorporated critique more clearly in their definitions and emphasized the importance of interpreting or making sense of data and evidence (Berland & Riser, 2009; McNeill at al., 2016; Sampson & Clark, 2008). In the case of Julie, she also noted that teaching students to critique different explanations was a more complex process than she had initially believed, but essential to scientific argumentation.

Jordan extended his view about scientific argumentation to include a key purpose of argumentation: persuasion (Berland & Reiser, 2009; Jiménez-Aleixandre & Erduran, 2007; Osborne & Patterson, 2011). Jordan especially noted that students assume they are writing for teachers to show their understanding of science rather than writing with the purpose of convincing the audience of their claim. Jordan viewed this as an important feature of argumentation to help students develop in their construction of arguments.

Mitch continued to view scientific argumentation as a battle or a fight, however, his view of scientific argumentation did address the issue of structure. Mitch mentioned that focusing on distinguishing components such as evidence from reasoning did little in teaching students to have effective arguments. Mitch's concerns about focusing on identifying parts of arguments in lieu of identifying the quality of scientific arguments echoes concerns about using TAP or other general argument structures to determine the quality of arguments over domain-specific frameworks (Faize et al., 2018; Sampson & Clark, 2008). Though Mitch saw argumentation as a generally negative activity in his classroom, his suggestions for collaborative discussions where student listen and build on each other's ideas align with definitions of scientific argumentation such as Andriessen and Baker's (2014) who claimed, "argumentation in science should not be primarily oppositional and aggressive; it is a form of collaborative discussion in which both parties are working together to resolve an issue, and which both scientists aim to reach agreement" (p. 443). Through the process of integrating argumentation over the course of three quarters, all teachers' definitions of argumentation developed in ways that match disciplinary ways of arguing.

Additionally, teachers' understanding of how to teach argumentation, or their pedagogical content knowledge (PCK) is important in appreciating how teachers incorporate argumentation into their classroom. Over the course of this study, all four teachers' understanding of argumentation and their PCK became more developed and complex. Teachers' beliefs about teaching argumentation came from the initial and final interviews, so it is unclear whether the teachers would enact their increased knowledge in the future, but in comparing their descriptions of how to teach argumentation in the two interviews, all of the teachers had much more detailed and nuanced explanations.

First, all teachers recognized the complexities of teaching and doing argumentation in a way they did not mention initially. It is important for teachers to recognize the complexity of argumentation in order to support students' argumentation

(Jonassen & Kim, 2010). Additionally, teachers who overlook the complexity of argumentation may over-simplify argumentation (McNeill et al., 2018). In all four cases, the teachers' recommendations at the end of the study included instructional strategies that would help students build up the skills necessary for argumentation. Jordan, Julie, and Mitch all mentioned that they had started too complexly or had underestimated the complexity of a specific task, such as addressing the counterclaim.

All of the teachers also recommended expanding the amount of argumentation and the features of their argumentation units. Julie especially noted the importance of teaching students how to critique each other's arguments through oral discussions. Jordan also emphasized giving students more time to develop arguments before assigning them to students. Andrew and Mitch both noted that students should be taught to equally examine two opposing views with the intent to identify the strongest one. In addition to other suggestions, all of the teachers mentioned specific ways they would change their instruction in upcoming years or what they would recommend to science teachers incorporating argumentation for the first time.

This developed understanding of argumentation and PCK reflect similar findings in other research that supporting teachers through reflection and feedback can help them develop understandings of teaching argumentation (Christodoulou & Osborne, 2014) This finding is also important in looking at how literacy coaching may be one way to support teachers as they engage in argumentation. Even with limited time in supporting the teachers, all of them recognized that literacy coaching, at the very least, motivated them to incorporate some argumentation into their instruction.

All of the teachers initially mentioned the importance of argumentation in their science classroom and emphasized the value specifically for helping students develop critical thinking and evaluate science-based information in their own lives. The one exception to this was Mitch. By the end of the study, Mitch was generally negative about the process of implementing argumentation in his classroom. This negativity was primarily based on the consequences of emphasizing argumentation as a fight. Mitch's negative experience in teaching argumentation echoes Kilinc et al.'s (2017) study of a preservice teacher whose lack of classroom management while engaging students in oral argumentation led her to doubt the value in teaching scientific argumentation. Negative experiences as teachers integrate argumentation into their classroom may play an important role in their continued use and beliefs about scientific argumentation. Research looking at ways to mitigate these negative experiences or support teachers when their implementation of scientific argumentation does not work as they intended could add to the research on PD for scientific argumentation.

Recommendations for Research and Education

Based on the findings from this multiple case study in the context of literacy coaching, there are several recommendations for future research and education. First, all of the teachers in this study incorporated some effective strategies for argumentation, and all of the teachers developed more nuanced beliefs about what quality features are important in high-quality scientific argumentation, and about how to teach argumentation. Both of these positive findings show that PD in the form of literacy coaching can offer an entry-point in helping teachers incorporate scientific argumentation into their instruction.

Second, all of the teachers' argumentation units excluded some important features. One of these exclusions was the use of inquiry and critique for argumentation. These features may have increased the complexity of argumentation, especially for teachers who had only used labs as step-by-step reinforcements of science concepts from their lectures. It is unclear if these teachers, as they developed more of an understanding of argumentation and their students' abilities, would have incorporated these types of strategies in a subsequent year. Research that looks at PD over the course of multiple years may give a better understanding of how teachers adapt and improve their argumentation instruction over time.

Additionally, these teachers were supported by a literacy coach with experience in language arts and history, but not science. This lack of expertise with science may have contributed to the teachers' emphasis on using texts as sources of data. Additional research looking at the ways literacy coaches can support science teachers with little experience in scientific argumentation could add to our understandings of the best PD to support science teachers.

Teachers' beliefs and experiences in this study did not inform their instruction in the way I anticipated. Instead, three of the teachers' beliefs did not match up with their experiences or the way they integrated scientific argumentation. This has important implications for PD. First, when teachers' experiences do not match up with their beliefs, they may default to traditional ways of instruction. Also, teachers who believe their instruction is not the best practice but have not changed or adapted it may need additional support to do so. This could include continued modeling from a coach with feedback to support teachers.

Finally, teachers who had no experience in student-centered practices established environments that made it difficult for their students to engage in argumentation. Disciplinary literacy coaching can support teachers in these types of practices through modeling instruction, as in Jordan's case. Supporting teachers in incorporating student-centered practices into their instruction before using argumentation may help students and teachers engage in argumentation in more effective ways.

Conclusion

The findings in this research showed that teachers' experiences and purposes play an important role in the ways they implement scientific argumentation. Importantly, teachers' purposes and experiences connected to how they used effective argumentation strategies such as direct instruction, scaffolding, and feedback. The differences among these teachers in the ways they incorporated scientific argumentation also point to the variability in the approaches teachers can use for scientific argumentation. This study emphasizes the multifaceted nature of scientific argumentation-- oral or written, formal or informal, from scientific texts or hands-on inquiry, small group or individual. Teachers who have little experience in doing scientific argumentation may feel overwhelmed by these types of decisions.

The results of this study indicated that when all teachers participated in PD with a disciplinary literacy coach, they all incorporated some effective strategies for argumentation, but excluded two important features. All of the teachers also showed a better understanding of instructional strategies for argumentation. In looking at the differences in how the teachers incorporated argumentation, their experiences played a clear role in both the features of the argumentation units, the purposes for teaching argumentation, and how the teachers used strategies like scaffolding and feedback.

The benefits of scientific argumentation are well established in science educational research, but the fact that science teachers rarely use scientific argumentation in their classes indicates the importance for both researchers and educators to help teachers engage in this essential practice. As Lemke (1990) wrote, “Teaching science is teaching how to *do science*. Teaching, learning and doing science are all social processes: taught, learned, and done as members of social communities, small (like classrooms) and large” (xi). To support teachers in helping their students “do science” and not just memorize science, this study can provide some important ways that teachers began the process of engaging their students in scientific argumentation and the ways their beliefs and experiences informed their instruction.

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Appendix A

Initial Interview Questions

Background

1. Could you describe your teaching history?

- How many years have you taught?
- How many of those years were in high school?
- Have you taught in other schools?
- What kinds of subjects have you taught?

2. Please describe your experience working at this school.

Perspectives related to content knowledge of argumentation

1. How would you define academic argumentation?

2. Could you give me an example of argumentation in science?

3. Have you practiced argumentation in your personal learning of science?

  a. Did you use argumentation in college courses?

  b. Do you read scientific arguments in your personal life?

Perspectives related to beliefs about science education

1. What are the main learning goals you have for your students in your biology course?
2. What kind of instructional practices do you use most often to help your students in learning biology?
3. Please describe the role (if any) you think argumentation should have in your biology course.

4. What do you think are the biggest challenges of teaching biology to tenth grade students?

Perspectives related to pedagogical content knowledge of argumentation

1. Could you describe any argumentation instruction you have used in your classroom?
2. How often do you use argumentation in your class?
3. What kinds of topics have you or could you use argumentation to teach?
4. What kinds of activities have you had your students do to engage in argumentation?

Perspectives related to professional development

1. What kinds of professional development have you received in the past 3 years?
   A. Have you participated in science specific professional development?
   - How was the professional development provided? (Meeting outside of school? Online instruction? Observing another teacher?)
   - Could you describe the activities or instruction you received?
   - Did the professional development influence your teaching? (If it did, in what ways did it influence your practice?)

   B. Have you participated in non-science specific professional development?
   - How was the professional development provided? (Meeting outside of school? Online instruction? Observing another teacher? Presentation to whole faculty?)
   - Could you describe the activities or instruction you received?

- How helpful do you think this professional development was in improving your classroom planning and instruction?

C. Have you participated in any professional development in using argumentation in science?

- Could you describe the activities or instruction you received?
- How helpful do you think this professional development was in improving your classroom planning and instruction?

Other

1. Is there anything else you want to add about your teaching experiences or thoughts about argumentation?

Appendix B

Final Interview Questions

Perspectives related to the role of argumentation in science

1. How would you define academic argumentation after participating in this professional development?
2. Could you give me an example of argumentation in science?
3. Please describe the role you think argumentation should have in your biology course.

Experience using argumentation

1. Which argumentation practices (strategies) did you find most valuable in teaching science to your students (if any)?
2. Which argumentation practices (strategies) did you find the least valuable (if any)?
3. How do you see yourself using argumentation in your science classes in upcoming years?
    a. What kinds of topics could you use argumentation to teach?
    b. What kinds of activities will you have your students do to engage in argumentation?

Perspectives related to professional development

1. How did this professional development model over the course of the year compare to other professional development experiences you have had in the past?
    a. How did this PD compare to science specific PD you have had in the past?

b. How did this PD compare to non-science specific professional development?

2. How do you think this coaching pd impacted your teaching (if at all)?

    a. Did it impact your knowledge level at all? If so, how?

    b. Did it impact what you did in class? If so, how?

    c. Did it impact the way you collaborated with other teachers? If so, how?

3. What were strengths and weaknesses of the coaching PD? (If any)

Other

Is there anything else you want to add about your experience participating in this professional development?

Appendix C

Teacher Instruction of Scientific Argumentation Observation Protocol

Observation Information

Teacher ____________________ Class Period ____________________

Subject ____________________ Date ____________________

Duration of the Instruction __________________________

CLASSROOM CHARACTERISTICS

# of students present: __________

Seating Arrangement
Front

Groupings

Duration of whole group activities:

Duration of small group activities:

Activity Overview

Provide a brief description of the way the lesson was designed to promote argumentation.

Include instructional goals of the lesson.

RECORD OF EVENTS

In the space provided keep a running record of the events that occurred during the class period including the materials used during the lesson.

Time	Description of Event

STRUCTURE OF SCIENTIFIC ARGUMENTS

How the teacher instructs students in the format of arguments such as the parts of an argument.

How did the teacher address terminology of arguments such as claim, evidence, counterarguments, etc.? **Circle here if NA** The teacher did not address terminology.	**Terms used:**
	Description of instruction:
How did the teacher address the features that should be	**Features addressed:**
	Description of instruction:

included in high quality arguments? **Circle here if NA** The teacher did not address high quality features.	
Additional notes:	

ORAL ARGUMENTATION

How the teacher supports students in developing oral arguments in whole group or small groups.

How did the teacher use questions to promote argumentation in whole or small group discussions? **Circle here if NA**	**Questions asked:**
	Description of instruction:

<table>
<tr><td>The teacher did not use questions to promote argumentation.</td><td></td></tr>
<tr><td rowspan="2">How did the teacher encourage student-centered argumentation in whole or small group discussions?

Circle here if NA
The teacher did not encourage student-centered argumentation</td><td>How often did the teacher interject his/her ideas?</td></tr>
<tr><td>Description of instruction:</td></tr>
<tr><td colspan="2">Additional notes:</td></tr>
</table>

WRITTEN ARGUMENTATION

How the teacher supports students in developing oral arguments in whole group or small groups.

How did the teacher scaffold written arguments for students such as graphic organizers, sentence starters, etc.	**Scaffolds used:**

Circle here if NA The teacher did not scaffold written arguments	**Description of instruction:**
How did the teacher use models of written arguments?	**Number and types of models:**
Circle here if NA The teacher did not use models of written arguments	**Description of instruction:**
Additional notes:	

EVALUATION OF ARGUMENTATION

How the teacher provides feedback about the quality of their oral or written arguments.

<table>
<tr><td>How did the teacher assess the quality of oral or written arguments?

Circle here if NA
The teacher did not assess the quality of arguments</td><td></td></tr>
<tr><td rowspan="2">How did the teacher indicate that arguments were of high quality?

Circle here if NA
The teacher did not indicate that arguments were of high quality</td><td>Scaffolds used:</td></tr>
<tr><td>Description of instruction:</td></tr>
<tr><td rowspan="2">How did the teacher help students improve low quality arguments?

Circle here if NA</td><td>Number and types of models:</td></tr>
<tr><td>Description of instruction:</td></tr>
</table>

The teacher did not help students improve low quality arguments	
Additional notes:	

Appendix D

Member Checking Protocol

Research Question 1: For each of the themes I found for the teacher, I will ask:

I was looking at how you taught scientific argumentation. I noticed that …

a. Would you add or change anything?
b. Do you think I've described what you did as a teacher accurately?

Research Question 2: For each of the themes I found for the teacher, I will ask:

I was also looking at what kinds of things influenced the way you taught scientific argumentation. I noticed that…

a. Would you add or change anything?
b. Do you think the factors I've mentioned accurately explain your actions as a teacher?

Overall: Is there anything else that I should add or change in describing how you taught scientific argumentation?

Appendix E

Julie's Argumentative Essay Requirements

3rd Quarter Essay

Should we be able to edit DNA in ourselves or in other organisms?

<u>Content to be included:</u>

1. What is DNA? **(Journal Entry 9)**

- What is DNA? How does its structure allow editing?
- How does DNA replication allow a change in DNA to spread?

2. How does DNA create traits?

- How does a change in DNA result in a change in a trait? **(Journal Entry 10)**
- How do genes and other factors interact to create traits? **(Journal Entry 10.5)**
- How do alleles interact to create traits? **(Journal Entry 11)**
- How do we inherit DNA?

3. How do we currently edit DNA? **(Journal Entry 12)**

- How do we use restriction enzymes to insert a gene?
- How do CRISPR and Prime change DNA?

4. Why do we currently edit DNA?

- Production of insulin
- GMO crops
- Medical uses

5. What are the benefits of editing DNA? What are the downsides? What are possible unintended consequences and how likely are they?

6. Do you think DNA editing should be legal? **(Write in class 3/2 or 3/3)**

- Explain the nuances of your answer: which organisms, for what purposes, after what kind of preparation/testing
- Support your position with scientific evidence and reasoning
- Include one counterargument and explain why your reasoning is stronger

Formatting Requirements:

- Use a standard font (ex. Times New Roman, Georgia, Ariel, Calibri) size 11 or 12.
- Use the default page setup settings:
  - 1" margins
  - 1.15 line spacing
  - Left justified
- Write your name and class period at the top
- You must have a title
- You may use headings to indicate the organization of your essay, but do not include the questions from the prompt
- If you use any images or quotes, they MUST be cited.
- There is no length requirement.

Template for DNA Editing Summative Essay

Introduction

- This should include your thesis!

How the Structure and Processes of DNA Allow Editing

How DNA is Inherited

The History of DNA Editing

Subcloning

CRISPR

Prime (CRISPR 2.0)

The Advantages and Disadvantages of Past DNA Editing

Evidence and Reasoning for [your thesis]

Counter Argument

Conclusion

- Make sure you restate your thesis and summarize the main points that support your thesis

Appendix F

Jordan's Cast Study of Cystic Fibrosis

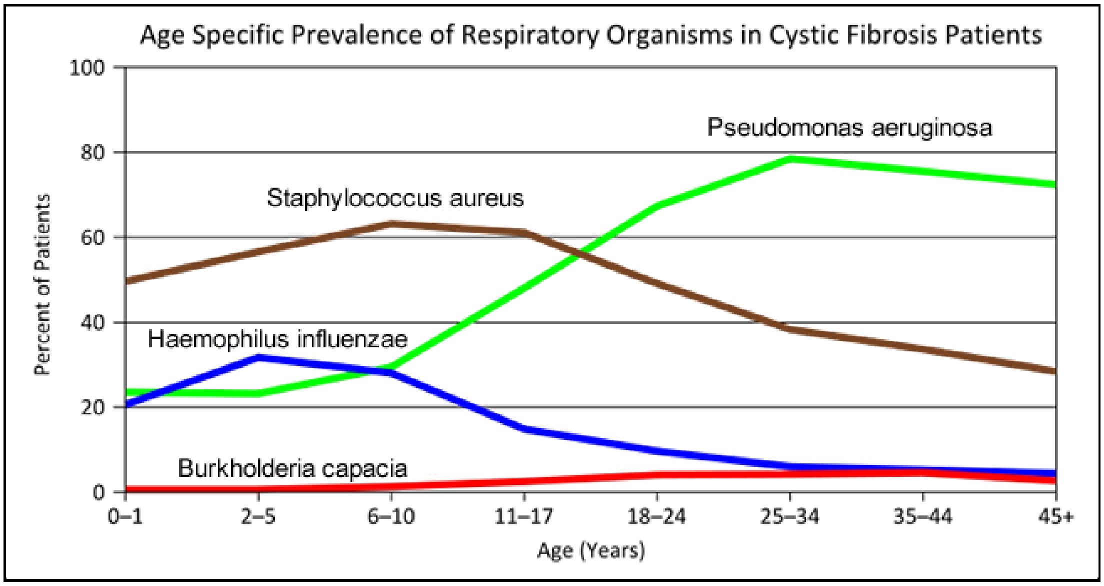
A Case of Cystic Fibrosis

Dr. Weyland examined a six month old infant that had been admitted to University Hospital earlier in the day. The baby's parents had brought young Zoey to the emergency room because she had been suffering from a chronic cough. In addition, they said that Zoey sometimes would "wheeze" a lot more than they thought was normal for a child with a cold. Upon arriving at the emergency room, the attending pediatrician noted that salt crystals were present on Zoey's skin and called Dr. Weyland, a pediatric pulmonologist. Dr. Weyland suspects that baby Zoey may be suffering from cystic fibrosis.

CF affects more than 30,000 kids and young adults in the United States. It disrupts the normal function of epithelial cells — cells that make up the sweat glands in the skin and that also line passageways inside the lungs, pancreas, and digestive and reproductive systems.

The inherited CF gene directs the body's epithelial cells to produce a defective form of a protein called CFTR (or cystic fibrosis transmembrane conductance regulator) found in cells that line the lungs, digestive tract, sweat glands, and genitourinary system.

When the CFTR protein is defective, epithelial cells can't regulate the way that chloride ions pass across cell membranes. This disrupts the balance of salt and water needed to maintain a normal thin coating of mucus inside the lungs and other passageways. The mucus becomes thick, sticky, and hard to move, and can result in infections from bacterial colonization.



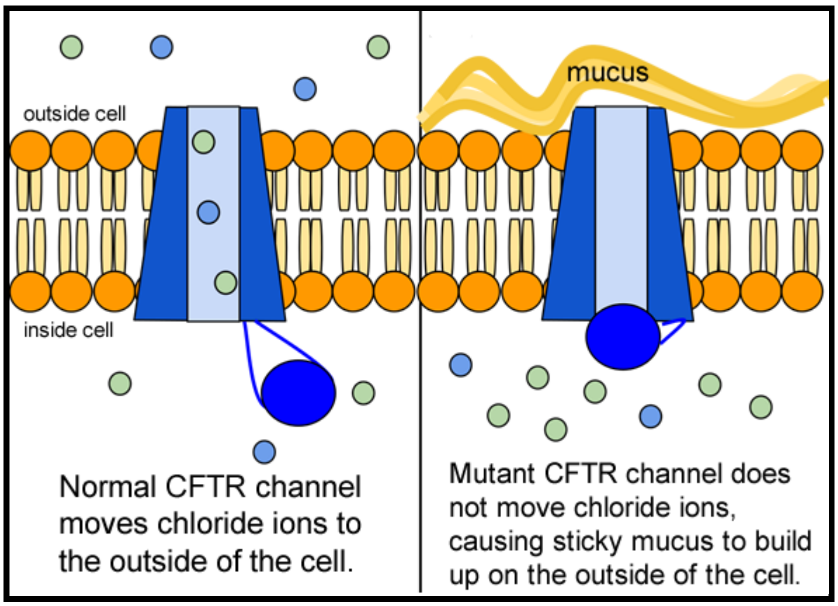
1. "Woe to that child which when kissed on the forehead tastes salty. He is bewitched and soon will die" This is an old saying from the eighteenth century and describes one of the symptoms of CF (salty skin). Why do you think babies in the modern age have a better chance of survival than babies in the 18th century?
2. What symptoms lead Dr. Weyland to his initial diagnosis?
3. Consider the graph of infections, which organism stays relatively constant in numbers over a lifetime. What organism is most likely affecting baby Zoey?
4. What do you think is the most dangerous time period for a patient with CF? Justify your answer.

Part II: CF is a disorder of the cell membrane.

Imagine a door with key and combination locks on both sides, back and front. Now imagine trying to unlock that door blind-folded. This is the challenge faced by David Gadsby, Ph.D., who for years struggled to understand the highly intricate and unusual cystic fibrosis chloride channel – a cellular doorway for salt ions that is defective in people with cystic fibrosis.

His findings, reported in a series of three recent papers in the Journal of General Physiology, detail the type and order of molecular events required to open and close the gates of the cystic fibrosis chloride channel, or as scientists call it, the cystic fibrosis transmembrane conductance regulator (CFTR).

Ultimately, the research may have medical applications, though ironically not likely for most cystic fibrosis patients. Because two-thirds of cystic fibrosis patients fail to produce the cystic fibrosis channel altogether, a cure for most is expected to result from research focused on replacing the lost channel.



5. Suggest a molecular fix for a mutated CFTR channel. How would you correct it if you had the ability to tinker with it on a molecular level?

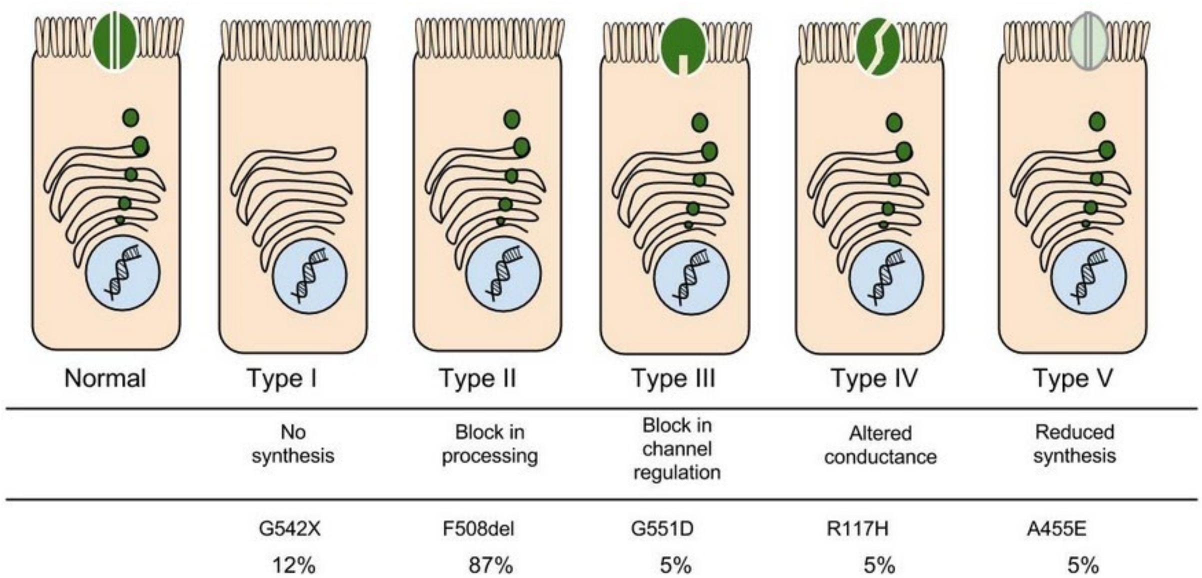
6. Why would treatment that targets the CFTR channel not be effective for ⅔ of those with cystic fibrosis?

7. Sweat glands cool the body by releasing perspiration (sweat) from the lower layers of the skin onto the surface. Sodium and chloride (salt) help carry water to the skin's surface and are then reabsorbed into the body. Why does a person with cystic fibrosis have salty tasting skin?

Part III: No cell is an island

Like people, cells need to communicate and interact with their environment to survive. One way they go about this is through pores in their outer membranes, called ion channels, which provide charged ions, such as chloride or potassium, with their own personalized cellular doorways. But, ion channels are not like open doors; instead, they are more like gateways with high-security locks that are opened and closed to carefully control the passage of their respective ions.

In the case of CFTR, chloride ions travel in and out of the cell through the channel's guarded pore as a means to control the flow of water in and out of cells. In cystic fibrosis patients, this delicate salt/water balance is disturbed, most prominently in the lungs, resulting in thick coats of mucus that eventually spur life-threatening infections. Shown below are several mutations linked to CFTR:



Mutation	Description
Class I	Gene contains a stop signal that prevents CFTR from being made.
Class II	CFTR is made, but does not reach the cell membrane
Class III	CFTR is made and in the right place, but does not function normally

Class IV	Channel does not move substances efficiently or at all
Class V	CFTR is made in smaller than normal quantities

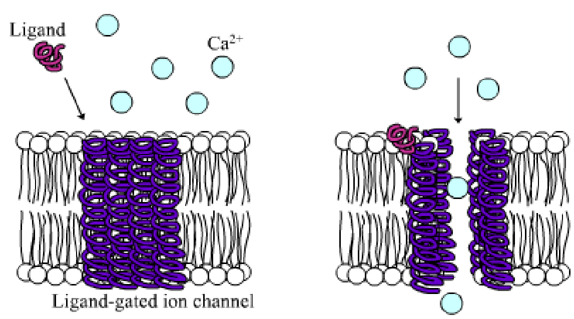
8. Which mutation do you think would be easiest to correct. Justify your answer.

9. Consider what you know about proteins, why does the “folding” of the protein matter?

Part IV: Opening the Channel

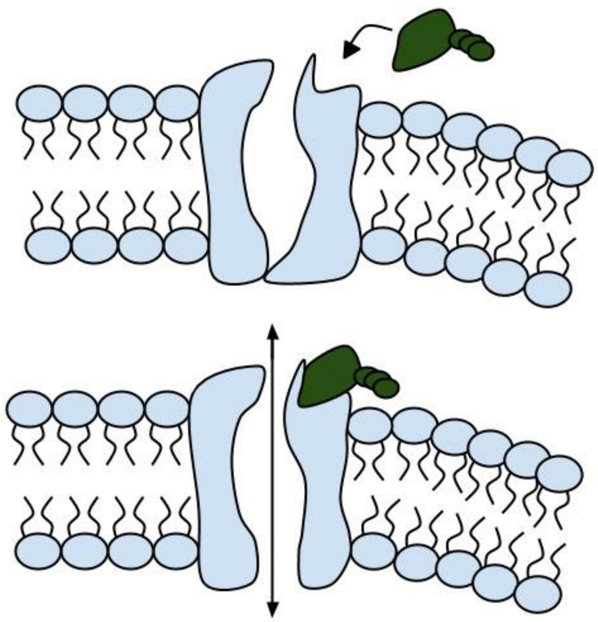
Among the numerous ion channels in cell membranes, there are two principal types: voltage-gated and ligand-gated. Voltage-gated channels are triggered to open and shut their doors by changes in the electric potential difference across the membrane. Ligand-gated channels, in contrast, require a special “key” to unlock their doors, which usually comes in the form of a small molecule.

CFTR is a ligand-gated channel, but it’s an unusual one. Its “key” is ATP, a small molecule that plays a critical role in the storage and release of energy within cells in the body. In addition to binding the ATP, the CFTR channel must snip a phosphate group – one of three “P’s” – off the ATP molecule to function. But when, where and how often this crucial event takes place has remains obscure.



10. Compare the action of the ligand-gated channel to how an enzyme works.

11. Consider the model of the membrane channel. What could go wrong to prevent the channel from opening?



12. Where is ATP generated in the cell? How might ATP production affect the symptoms of cystic fibrosis?

13. Label the image to the right to show how the ligand-gated channel for CFTR works. Include a summary in the space below.

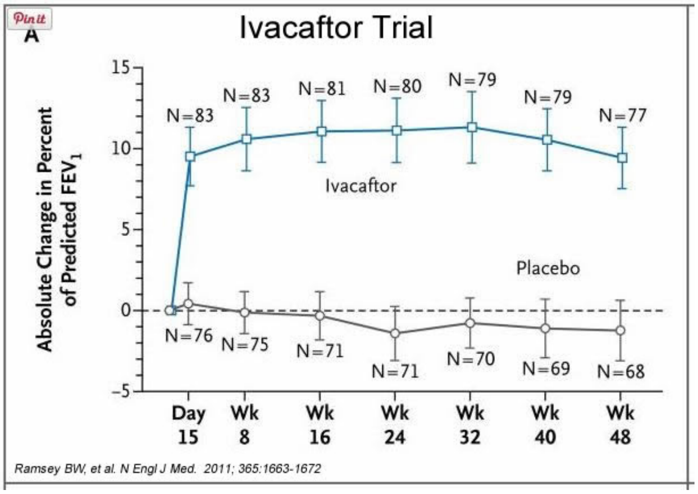
Part V: Can a Drug Treat Zoey's Condition?

Dr. Weyland confirmed that Zoey does have cystic fibrosis and called the parents in to talk about potential treatments. "Good news, there are two experimental drugs that have shown promise in CF patients. These drugs can help Zoey clear the mucus from her lungs. Unfortunately, the drugs do not work in all cases." The doctor gave the parents literature about the drugs and asked them to consider signing Zoey up for trials.

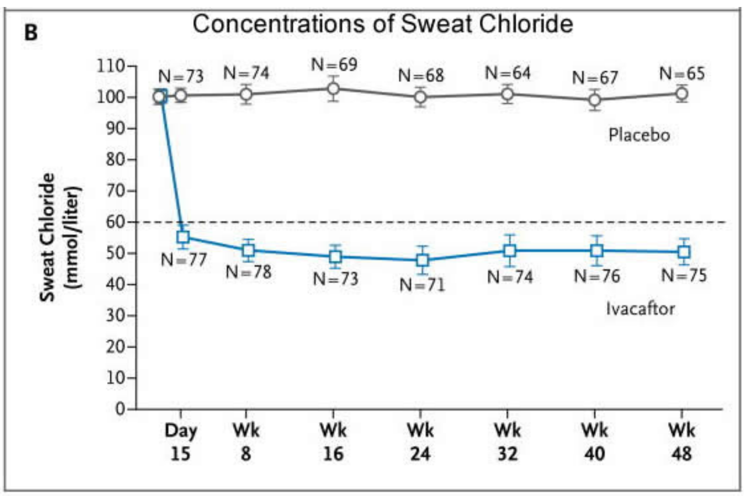
The Experimental Drugs

Ivacaftor ™ is a potentiator that increases CFTR channel opening time. We know from the cell culture studies that this increases chloride transport by as much as 50% from baseline and restores it closer to what we would expect to observe in wild-type CFTR. Basically, the drug increases CFTR activity by unlocking the gate that allows for the normal flow of salt and fluids.

In early trials, 144 patients all of whom were over the age of 12 were treated with 150 mg of Ivacaftor twice daily. The total length of treatment was 48 weeks. Graph A shows changes in FEV (forced expiratory volume) with individuals using the drug versus a placebo. Graph B shows concentrations of chloride in patient's sweat.



Ramsey BW, et al. N Engl J Med. 2011; 365:1663-1672



14. What is FEV? Describe a way that a doctor could take a measurement of FEV.

15. Why do you think it was important to have placebos in both of these studies?

16. Which graph do you think provides the most compelling evidence for the effectiveness of Ivacaftor? Defend your choice.

17. Take a look at the mutations that can occur in the cell membrane proteins from Part III. For which mutation do you think Ivacaftor will be most effective? Justify your answer.

18. Would you sign Zoey up for clinical trials based on the evidence? What concerns would a parent have before considering an experimental drug?

Part VI: Zoey's Mutation

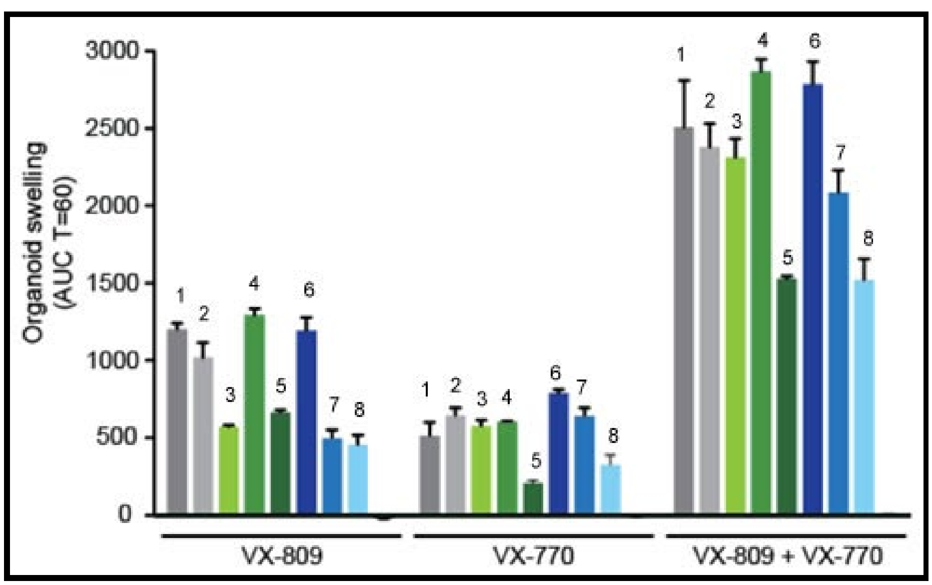
Dr. Weyland calls a week later to inform the parents that genetic tests show that Zoey chromosomes show that she has two copies of the F508del mutation. This mutation, while the most common type of CF mutation, is also one that is difficult to treat with just Ivacaftor.

Ivacaftor and Lumacaftor

In people with the most common CF mutation, a series of problems prevents the CFTR protein from taking its correct shape and reaching the cell surface. Two drugs have been found to treat the problems. VX-809, or Lumacaftor, was shown to help with the trafficking of the protein to the surface of the membrane. VX-770, or Ivacaftor, could open the channels. Many treatments of CF involved a combination of these two drugs.

The drugs may not work on each phenotype. A new type of research uses rectal organoids (mini-guts) grown from the patient that would be treated with the drug. These experiments are personalized medicine, a way to determine which drug will have the best outcome.

20. The graph below shows how each drug works for 8 different patients (#1-#8). Organoid swelling indicates the effectiveness of the drug at moving Annotate the graph and provide a short 1 sentence caption that summarizes the main idea being illustrated by the graph.



21. (CER) If the profile labeled #7 is Zoey, rank the possible drug treatments in order of their effectiveness for her mutation. This is your **CLAIM.**

Provide **EVIDENCE** to support your claim

Provide **REASONING** that explains why this treatment would be more effective than other treatments and why what works for Zoey may not work for other patients. This is where you tie the graph above to everything you have learned in this case and to information about the cell membrane and cell processes.

Source: http://newswire.rockefeller.edu/2003/12/19/scientists-finally-pry-stubborn-cellular-door-ajar/

http://en.wikipedia.org/wiki/Cystic_fibrosis

http://www.medscape.org/viewarticle/806649_transcript

http://www.cff.org/research/clinicalresearch/faqs/combinedkalydeco-vx-809/#Expanded-Access

Ifacaftor Trial Graph: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3230303/

Organoid swelling graph: http://www.potentiate.info/?q=trio-clinical-trial-ivacaftor-genistein

Appendix G

Mitch's Oral Debate Format

Mitch orally described this process to his students and listed the roles on the board.

The class was split into two and assigned a position on the use of genetic testing for criminal cases.

Day 1: Preparation Day

Each student was assigned a Google slide for their role and given the class period to complete it.

Student Roles

- Leader: End speaker for the group and group organizer
- Debate recorder: Keeps track of things said during the debate
- Devil's advocate: Develops possible counter arguments
- Angel's advocate: Develops responses to the counter arguments
- Pure researchers: Search for information to support their side
- Source Analyzers: Evaluate the sources where researchers are finding their information

Day 2: Debate Day

Debate Format

Each student must speak twice except the debate record

Opening Arguments: Each team will choose an opening speaker to present the arguments for their side.

Recess: After both of the opening arguments are presented, students will have 5 minutes to regroup and plan their response as a team.

Open Floor: Each side will take turns responding to the other group. Groups will take turns debating each other. If no one has anything to say from one team, the other team can make another statement.

Winners: The teacher takes notes during the debate and awards points to each side. The Google slides for each team will also be used to determine the winner.

CURRICULUM VITAE

Ashley Strong
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EDUCATION

2022: Ph. D, Teacher Education and Leadership
Utah State University, Logan, Utah
Curriculum and Instruction
Literacy Education and Leadership

2012: Master of Arts, English
Weber State University, Ogden, Utah

2005: Bachelor of Arts, English and History.
Weber State University, Ogden, Utah

CERTIFICATIONS AND ENDORSEMENTS

2015: Level I Reading Endorsement

2007: Secondary Teaching Certification, English and History
Weber State University, Ogden, Utah

PROFESSIONAL EXPERIENCE

2007—present High school teacher and Literacy coach, Weber School District

Courses Taught

AP Language and Composition (2008-present), AP World History (2015- 2018), Creative Writing 10-12 (2008-2009), CE ENG 1010 (2021-2022), CE ENG 2015 (2021-2022), Honors Language Arts 10 (2012-2014), Language Arts 10 (2007- present), World Civilizations 10 (2007-2015), Language Arts 10 PM School (2007-2017), Language Arts 11 PM School (2007-2017), World Civilizations PM School (2013-2017).

2013, 2014,
2015,
2020-2022: AP Language and Composition Reader, ETS

2017—2018: Adjunct Instructor, Utah State University
Language, Literacy, and Learning in the Content Areas

2018—2021: Graduate Research Assistant at Utah State University.

PUBLICATIONS

PEER-REVIEWED JOURNAL ARTICLES

Mohr, K.A., Ding, G., Strong, A., Branum, L., Watson, N., Priestley, K. L., … Lundstrom, K. (2017). Reading the past to inform the future: 25 years of the reading teacher. *The Reading Teacher, 71*(3), 251-264.

Christensen-Branum, L., Strong, A., Jones, C. D. (2018). Mitigating myside bias in argumentation. *Journal of Adolescent and Adult Literacy, 62*(4), 435-445.

Wilson-Lopez, A., Strong, A., Hartman, C., Garlick, J., Washburn, K., Minichiello, A., Weingart, S., Acosta-Feliz, J. (2020). A systematic review of argumentation related to the engineering-designed world. *Journal of Engineering Education, 109*, 281-306.

PEER-REVIEWED CONFERENCE PROCEEDINGS

Wilson-Lopez, A., Sias, C., Garlick, J., Winegart, S., Minichiello, A., Acosta Feliz, J., & Strong, A. (2018). Argumentation in K-12 engineering education: A review of the literature. *Conference Proceedings of the American Society for Engineering Education,* Salt Lake City, UT.

Wilson-Lopez, A., Strong, A., Sias, C., Garlick, J. Minichiello, A., Winegart, S., & Acosta Feliz, J. (2018, December). *A systematic review of engineering education.* Paper presented at the annual meeting of the Literacy Research Association, Palm Springs, CA.

Strong, A., & Wilson-Lopez, A. (2019). Middle school engineering teachers' literacy instruction. *Conference Proceedings of the American Society for Engineering Education,* Tampa, FL. Retrieved from: https://www.asee.org/public/conferences/140/papers/26998/view

PRESENTATIONS

Christensen-Branum, L., Strong, A., (2017, November). *Battling "Myside Bias" in Argumentative Writing.* Workshop presented at the annual conference of *Utah Council of Teachers of English*, Sandy, UT.

Strong, A., Mathis, W. (2018, November). *The power of purpose: Providing student writers with a sense of ownership.* Workshop presented at the annual conference of *Utah Council of Teachers of English*, Sandy, UT.

Strong, A., Wilson-Lopez, A., (2019, October). *Literacy-infused engineering for middle school and elementary students.* Workshop presented at the regional conference of the *National Science Teachers Association*, Salt Lake City, UT.

Strong, A., Greenwood, G., Bartlett, A. (2019, June). *College Course 911.* Workshop presented at the *Utah FCS Pathways Summer Conference*, Saratoga Springs, UT.

Wilson-Lopez, A., Strong, A. (2019, December). *Middle school engineering teachers' perceptions and practices of disciplinary literacy.* Paper presented at the annual meeting of the Literacy Research Association, Tampa, FL.

Strong, A. (2020). Coaching for argumentation in high school biology. Paper presented at the annual meeting of the Literacy Research Association, Virtual Conference.

Wilson-Lopez, A., Strong, A., Minichiello, A., & Green, T. (2021, April). Expansive transmediation toward transformative epistemic practices in disciplinary literacy pedagogies. Symposium section presented at the virtual annual meeting of the American Educational Research Association.

Strong, A., Washburn, K., & Wilson-Lopez, A. (2021, December). Disciplinary literacies in engineering: Affirming the role of context and community in problem scoping. Paper presented at the annual meeting of the Literacy Research Association, Atlanta GA.